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PRECISE LINEAR SUN SENSC...



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June 9, 1972

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*Marshall Space Flight Center, Alabama*

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16. ABSTRACT

An evaluation of the precise linear sun sensor relating to future mission applications was performed. The test procedures, data, and results of the dual-axis, solid-state system are included. Brief descriptions of the sensing head and of the system's operational characteristics are presented. A unique feature of the system is that multiple sensor heads with various fields of view may be used with the same electronics.

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# PRECISE LINEAR SUN SENSOR

## INTRODUCTION

The precise linear sun sensor (PLSS) is a dual-axis, solid-state system that linearly converts an angle, $\theta$, into an output voltage, $V_0$. Silicon detectors are used as the system's sensing elements. The system uses geometry and an electronic divider to change the dimensions of the energized area of the silicon detectors. The PLSS is designed to compute the output voltage as the ratio of

$$V_0 = \frac{V_A - V_B}{V_A + V_B} ,$$

where $V_A$ and $V_B$ are the voltages of the two opposing sensors (detectors). Figure 1 shows a simplified sketch of the two-axis sensor. A more detailed analysis of the PLSS is given in Appendix A.

The sensor characteristics of the PLSS are listed thus:

| | |
|---|---|
| Sensor type: | Silicon — no moving parts |
| Operating range: | ±30 deg or ±10 deg |
| Acquisition range: | Double the operating range |
| Response time: | 0.005 s |
| Size: | 7.6 cm by 8.9 cm by 8.9 cm |
| Weight: | 0.68 kg |
| Accuracy: | 0.15 percent of operating range |
| Power: | 1 W from ±15 Vdc |
| Scale factor: | ±30 deg 0.333 V/deg; ±10 deg 1.000 V/deg |

The PLSS, developed by Honeywell Radiation Center (HRC), was loaned to MSFC for study and evaluation. Two sensor heads were supplied by HRC. One sensor head had a ±30 deg field of view (FOV) and the other had a ±10 deg FOV. Both sensor heads used the same set of electronics. Figure 2 shows a sensor head and its accompanying electronics.

The PLSS was tested by rotating the sensing head (which was in a beam of collimated light) through a known angle and recording the output ($V_0$) for the known angle.

# PROCEDURE

The PLSS was tested in the Celestial Facility utilizing the heliostat developed by the Astrionics Laboratory to supply the solar illumination (Fig. 3).

The PLSS was held by a group of precision dividing heads so that precision positioning in any axis, to an accuracy of ≈ 2 arc-sec, could be obtained (Figs. 4, 5, and 6).

Both axes of the PLSS were tested for linearity over their entire FOV. The pitch axis of the ±10 deg sensor was tested while the yaw axis was held stationary at null, ±5 deg, and ±10 deg, respectively. The pitch axis of the ±30 deg sensor was tested while the yaw axis was held stationary at null, ±15 deg, and ±30 deg, respectively. The same electronics were used with both the ±10 deg FOV and the ±30 deg FOV heads. This procedure was repeated with the words pitch and yaw interchanged to test the yaw axis of each sensor head.

To minimize translation errors, all data were taken by rotating the sensing unit about the horizontal axis (Leitz head).

The optical mechanical table (OMT) vertical axis was used to provide the desired angular offset (from null) of the nonsensitive axis. For example, if the yaw axis was being tested, the OMT (pitch axis) would be held stationary as the yaw axis was tested at various voltages from +10 V to -10 V. The voltage was recorded for the appropriate angle of the sensitive axis. The voltage output of the system was averaged for a 10 s interval by a Dymec model 2401C integrating voltmeter.

During the early phase of evaluation, a number of discrepancies were observed in the test results. Scattered light was the major cause of these discrepancies. Extensive shielding was required to assure that only desirable illumination reached the sensor head.

To improve the test apparatus, a piece of optical quality glass was installed between the sensing unit and the heliostat. A barrier was constructed to prevent the mass exodus of warm air to the outside. This greatly improved the thermal jitter.

# RESULTS

The best method of showing the linearity of the PLSS would have been to plot the raw data, but this method would have required an excessively large graph to show the error of the system. Instead, a table of the data is included for each axis so that a quick comparison of the voltage output of the system from -10 V to +10 V can be easily made (Tables 1 through 4).

The material shown in Figures 7 through 12 was determined as follows. The average scale factor of the sensitive axis with the nonsensitive axis at null was determined. The appropriate constant (K) to make the scale factor equal 1 V/deg was selected. The raw ($V_0$) data were multiplied by the previously determined K. For data where the nonsensitive axis was not at null, the raw data were multiplied by $\frac{K}{\cos \delta}$ where $\delta$ was the angle at which the nonsensitive axis was rotated from null; i.e., the raw data were actually corrected by $\frac{K}{\cos \delta}$.

The test data for evaluation of the PLSS are presented in Appendix B.

An ideal voltage of 1 V/deg of rotation was assumed. The graphs plotted consist of the ideal volts minus the direct volts $(V_0) \times \frac{K}{\cos \delta}$ versus deg rotation. Since the scale factor of the two axes (pitch and yaw) was different, a different K was used for each axis. The aforementioned method was used with the ±10 deg sensing unit. The ±30 deg sensing unit was treated in similar fashion but an ideal scale factor of 0.33333 V/deg was used and the appropriate K was selected to make the average null data scale factor equal 0.33333 V/deg.

The 0.1 deg accuracy of each PLSS sensing unit is equivalent to 0.33 V and 0.100 V for the ±30 deg head and the ±10 deg head, respectively.

The graphed material indicates that a K selected where the nonsensitive axis had an output of 5 V would probably have been a better choice, since the zero-to-peak error signal would have been decreased.

The largest direct voltage ($V_0$) spread between the null reading and the extreme angle reading for the ±10 deg FOV head was 0.115 V. The largest direct voltage ($V_0$) spread between the null reading and the extreme angle reading for the ±30 deg FOV head exceeded 1 V in every case (Tables 3 and 4).

The ±10 deg FOV head had a worst-case error of approximately ±0.1 deg when the direct voltage ($V_0$) output was corrected by $\frac{K}{\cos \delta}$. The ±30 deg FOV head had an error of approximately 1.2 deg at the extremes for the corrected data $\left(\frac{K}{\cos \delta}\right)$. The null crossing error varied considerably (0.110 V) for the yaw axis of the ±30 deg FOV head.

# CONCLUSION

The PLSS system has a number of very good features, such as its size, weight, and simplicity. The four silicon detectors are all etched at the same time and from the same chip, and each has the same substrate. This fact guarantees greater stability and uniformity of output for alignment, temperature variation, natural deterioration, etc.

Another favorable point of the PLSS system is that both the fine and coarse sensors use the same electronics. This is a simple and economical arrangement for a system that needs both a fine and coarse sun sensor. By proper interconnection, multiple redundancy can be obtained with two coarse sensor heads, two fine sensor heads, and two sets of electronics.

Although the PLSS did not achieve the 0.1 deg accuracy for all values of $\theta$ and $\phi$ as specified by the manufacturer, the system shows considerable promise. With a sufficient refinement of the mask and improvement in the electronics, this system should be suitable for a space mission such as the High Energy Astronomical Observatory at a much reduced cost to the program.

The error of the system would be reduced if the FOV of the PLSS was specified as a 30 deg half-angle cone. The extreme angle of the 30 deg by 30 deg FOV converts to an actual angle of 39 deg.

TABLE 1. YAW SENSITIVE AXIS ±10 DEG HEAD

| Sensitive Yaw Axis (deg) | Pitch Nonsensitive Axis | | | | | Extreme Spread (V) |
|---|---|---|---|---|---|---|
| | -10 deg | -5 deg | Null | +5 deg | +10 deg | |
| +10 | 9.984 | 10.028 | 10.036 | 10.022 | 9.960 | 0.076 |
| + 9 | 8.980 | 9.057 | 9.075 | 9.050 | 8.969 | 0.106 |
| + 8 | 7.969 | 8.040 | 8.061 | 8.041 | 7.972 | 0.092 |
| + 7 | 6.957 | 7.038 | 7.050 | 7.032 | 6.973 | 0.093 |
| + 6 | 5.948 | 6.031 | 6.049 | 6.030 | 5.975 | 0.101 |
| + 5 | 4.946 | 5.034 | 5.052 | 5.032 | 4.980 | 0.106 |
| + 4 | 3.950 | 4.040 | 4.056 | 4.033 | 3.985 | 0.106 |
| + 3 | 2.950 | 3.041 | 3.058 | 3.031 | 2.991 | 0.108 |
| + 2 | 1.951 | 2.028 | 2.047 | 2.021 | 1.993 | 0.096 |
| + 1 | +0.953 | + 1.015 | 1.028 | 1.012 | 1.004 | 0.075 |
| Null | -0.044 | - 0.001 | - 0.001 | - 0.005 | +0.010 | 0.043 |
| - 1 | -1.042 | - 1.025 | - 1.030 | - 1.021 | -0.981 | 0.049 |
| - 2 | -2.040 | - 2.046 | - 2.056 | - 2.039 | -1.981 | 0.075 |
| - 3 | -3.036 | - 3.061 | - 3.077 | - 3.052 | -2.976 | 0.101 |
| - 4 | -4.025 | - 4.059 | - 4.069 | - 4.044 | -3.967 | 0.102 |
| - 5 | -5.012 | - 5.043 | - 5.052 | - 5.032 | -4.956 | 0.096 |
| - 6 | -5.998 | - 6.029 | - 6.037 | - 6.018 | -5.945 | 0.092 |
| - 7 | -6.984 | - 7.018 | - 7.028 | - 7.007 | -6.932 | 0.096 |
| - 8 | -7.973 | - 8.009 | - 8.016 | - 7.999 | -7.922 | 0.094 |
| - 9 | -8.964 | - 9.006 | - 9.015 | - 8.995 | -8.918 | 0.097 |
| -10 | -9.979 | -10.021 | -10.027 | -10.012 | -9.940 | 0.087 |

TABLE 2. PITCH SENSITIVE AXIS ±10 DEG

| Sensitive Pitch Axis (deg) | Yaw Nonsensitive Axis | | | | | Extreme Spread (V) |
|---|---|---|---|---|---|---|
| | -10 deg | -5 deg | Null | +5 deg | +10 deg | |
| +10 | 9.974 | 10.025 | +10.032 | 10.024 | +9.980 | 0.058 |
| + 9 | 8.997 | 9.058 | + 9.073 | 9.057 | 8.985 | 0.088 |
| + 8 | 8.000 | 8.050 | + 8.061 | 8.050 | 7.981 | 0.080 |
| + 7 | 7.001 | 7.043 | + 7.051 | 7.041 | 6.972 | 0.079 |
| + 6 | 6.002 | 6.041 | + 6.049 | 6.039 | 5.964 | 0.085 |
| + 5 | 5.007 | 5.042 | + 5.051 | 5.042 | 4.965 | 0.086 |
| + 4 | 4.009 | 4.042 | + 4.058. | 4.050 | +3.970 | 0.088 |
| + 3 | +3.013 | 3.042 | + 3.057 | 3.051 | +2.972 | 0.085 |
| + 2 | +2.017 | 2.031 | + 2.046 | 2.043 | +1.978 | 0.068 |
| + 1 | +1.027 | 1.024 | + 1.028 | 1.028 | +0.985 | 0.043 |
| Null | +0.034 | + 0.012 | + 0.004 | + 0.003 | -0.017 | 0.030 |
| - 1 | -0.961 | - 1.009 | - 1.027 | - 1.014 | -1.009 | 0.066 |
| - 2 | -1.963 | - 2.028 | - 2.050 | - 2.034 | -2.008 | 0.087 |
| - 3 | -2.957 | - 3.038 | - 3.071 | - 3.051 | -3.003 | 0.114 |
| - 4 | -3.949 | - 4.032 | - 4.064 | - 4.045 | -3.988 | 0.115 |
| - 5 | -4.941 | - 5.024 | - 5.048 | - 5.029 | -4.975 | 0.107 |
| - 6 | -5.931 | - 6.011 | - 6.035 | - 6.018 | -5.962 | 0.104 |
| - 7 | -6.918 | - 7.003 | - 7.025 | - 7.002 | -6.943 | 0.107 |
| - 8 | -7.910 | - 7.993 | - 8.013 | - 7.993 | -7.963 | 0.103 |
| - 9 | -8.907 | - 8.988 | - 9.013 | - 8.988 | -8.921 | 0.106 |
| -10 | -9.933 | -10.006 | -10.026 | -10.006 | -9.938 | 0.093 |

TABLE 3. YAW SENSITIVE AXIS ±30 DEG

| Sensitive Yaw Axis (deg) | Pitch Nonsensitive Axis | | | | | Extreme Spread (V) |
|---|---|---|---|---|---|---|
| | -30 deg | -15 deg | Null | +15 deg | +30 deg | |
| +30 | 9.045 | +9.777 | 10.015 | 9.731 | +8.879 | 1.136 |
| +27 | 8.166 | 8.785 | 8.973 | 8.746 | +7.993 | 0.980 |
| +24 | 7.276 | 7.802 | 7.961 | 7.765 | +7.098 | 0.863 |
| +21 | 6.378 | 6.819 | 6.952 | 6.785 | +6.202 | 0.750 |
| +18 | 5.474 | 5.841 | 5.950 | 5.811 | +5.308 | 0.642 |
| +15 | 4.566 | 4.862 | 4.957 | 4.840 | +4.412 | 0.545 |
| +12 | 3.660 | 3.894 | 3.974 | 3.871 | +3.516 | 0.458 |
| + 9 | 2.759 | 2.932 | 3.001 | 2.911 | +2.619 | 0.382 |
| + 6 | 1.847 | +1.958 | 2.022 | 1.939 | +1.724 | 0.298 |
| + 3 | 0.933 | +0.971 | 1.019 | 0.961 | +0.828 | 0.191 |
| Null | +0.025 | -0.018 | + 0.001 | -0.023 | -0.085 | 0.086 |
| - 3 | -0.885 | -1.004 | - 1.022 | -1.010 | -0.991 | 0.137 |
| - 6 | -1.791 | -1.988 | - 2.040 | -1.996 | -1.900 | 0.249 |
| - 9 | -2.694 | -2.966 | - 3.042 | -2.974 | -2.808 | 0.348 |
| -12 | -3.595 | -3.930 | - 4.016 | -3.940 | -3.709 | 0.421 |
| -15 | -4.491 | -4.892 | - 4.992 | -4.900 | -4.610 | 0.501 |
| -18 | -5.394 | -5.861 | - 5.972 | -5.863 | -5.506 | 0.578 |
| -21 | -6.304 | -6.836 | - 6.964 | -6.835 | -6.404 | 0.660 |
| -24 | -7.217 | -7.825 | - 7.977 | -7.814 | -7.302 | 0.760 |
| -27 | -8.217 | -8.815 | - 8.998 | -8.803 | -8.194 | 0.804 |
| -30 | -9.030 | -9.804 | -10.044 | -9.787 | -9.070 | 1.014 |

TABLE 4. PITCH SENSITIVE AXIS ±30 DEG

| Sensitive Pitch Axis (deg) | Yaw Nonsensitive Axis | | | | | Extreme Spread (V) |
|---|---|---|---|---|---|---|
| | -30 deg | -15 deg | Null | +15 deg | +30 deg | |
| +30 | +8.690 | +9.563 | +9.742 | +9.477 | +8.778 | 1.052 |
| +27 | +7.842 | +8.575 | +8.719 | +8.511 | +7.890 | 0.877 |
| +24 | +6.986 | +7.612 | +7.733 | +7.557 | +7.002 | 0.747 |
| +21 | +6.118 | +6.656 | +6.752 | +6.606 | +6.116 | 0.636 |
| +18 | +5.248 | +5.703 | +5.776 | +5.654 | +5.227 | 0.549 |
| +15 | +4.380 | +4.753 | +4.813 | +4.710 | +4.344 | 0.469 |
| +12 | +3.506 | +3.815 | +3.862 | +3.773 | +3.470 | 0.392 |
| + 9 | +2.629 | +2.879 | 2.918 | +2.836 | +2.595 | 0.323 |
| + 6 | +1.750 | +1.930 | 1.960 | +1.892 | +1.715 | 0.245 |
| + 3 | +0.869 | 0.974 | +0.983 | +0.945 | +0.832 | 0.151 |
| Null | -0.006 | +0.017 | -0.002 | -0.005 | -0.050 | 0.048 |
| - 3 | -0.879 | -0.943 | -0.938 | -0.952 | -0.932 | 0.059 |
| - 6 | -1.748 | -1.899 | -1.959 | -1.895 | -1.825 | 0.211 |
| - 9 | -2.615 | -2.850 | -2.919 | -2.838 | -2.712 | 0.304 |
| -12 | -3.478 | -3.786 | -3.864 | -3.773 | -3.592 | 0.386 |
| -15 | -4.337 | -4.718 | -4.806 | -4.702 | -4.472 | 0.469 |
| -18 | -5.200 | -5.663 | -5.763 | -5.642 | -5.353 | 0.563 |
| -21 | -6.063 | -6.612 | -6.734 | -6.582 | -6.232 | 0.671 |
| -24 | -6.924 | -7.566 | -7.710 | -7.527 | -7.110 | 0.786 |
| -27 | -7.785 | -8.525 | -8.695 | -8.480 | -7.986 | 0.910 |
| -30 | -8.645 | -9.495 | -9.708 | -9.436 | -8.855 | 1.063 |

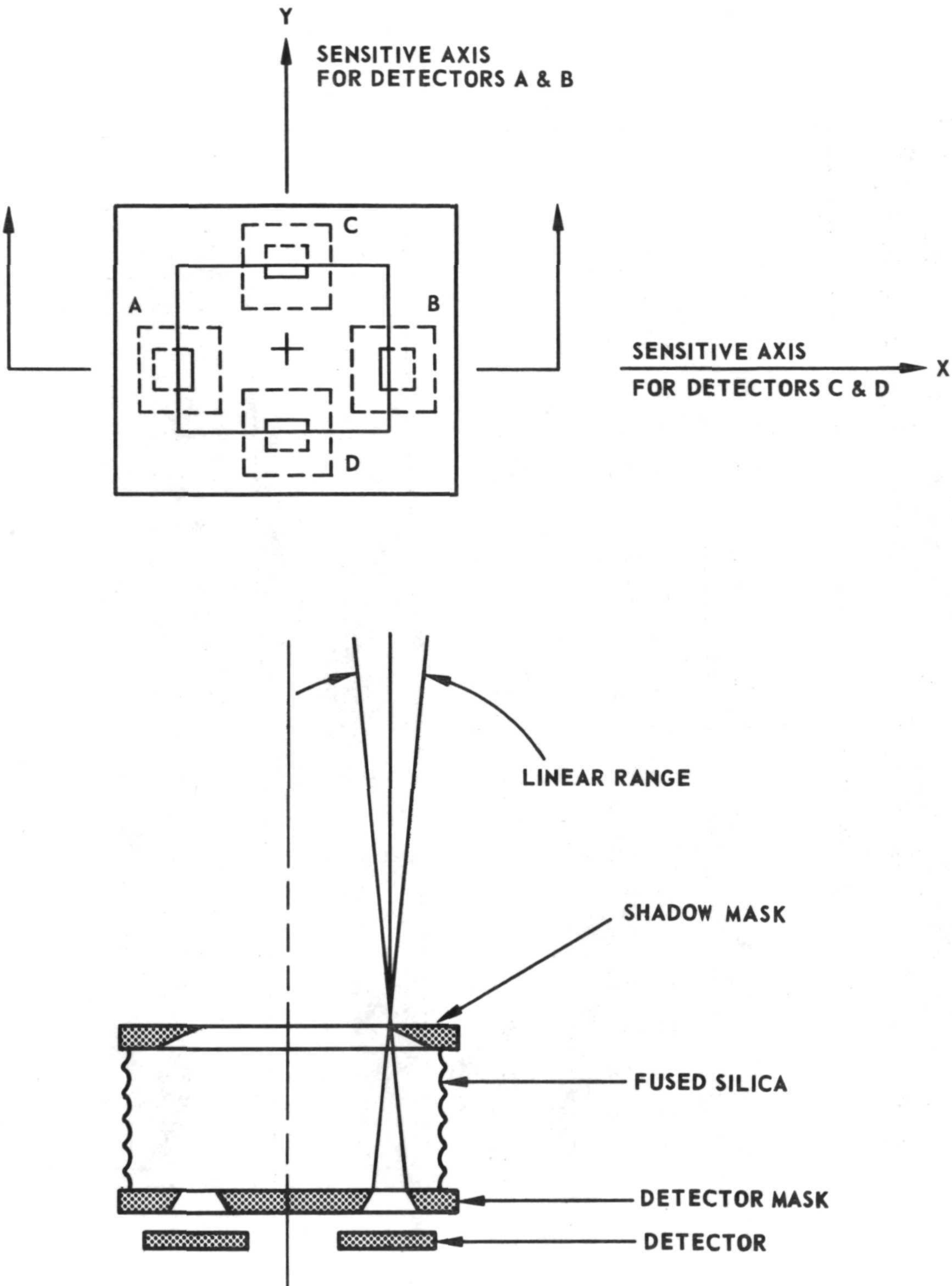


Figure 1. Simplified sketch of two-axis sensor.

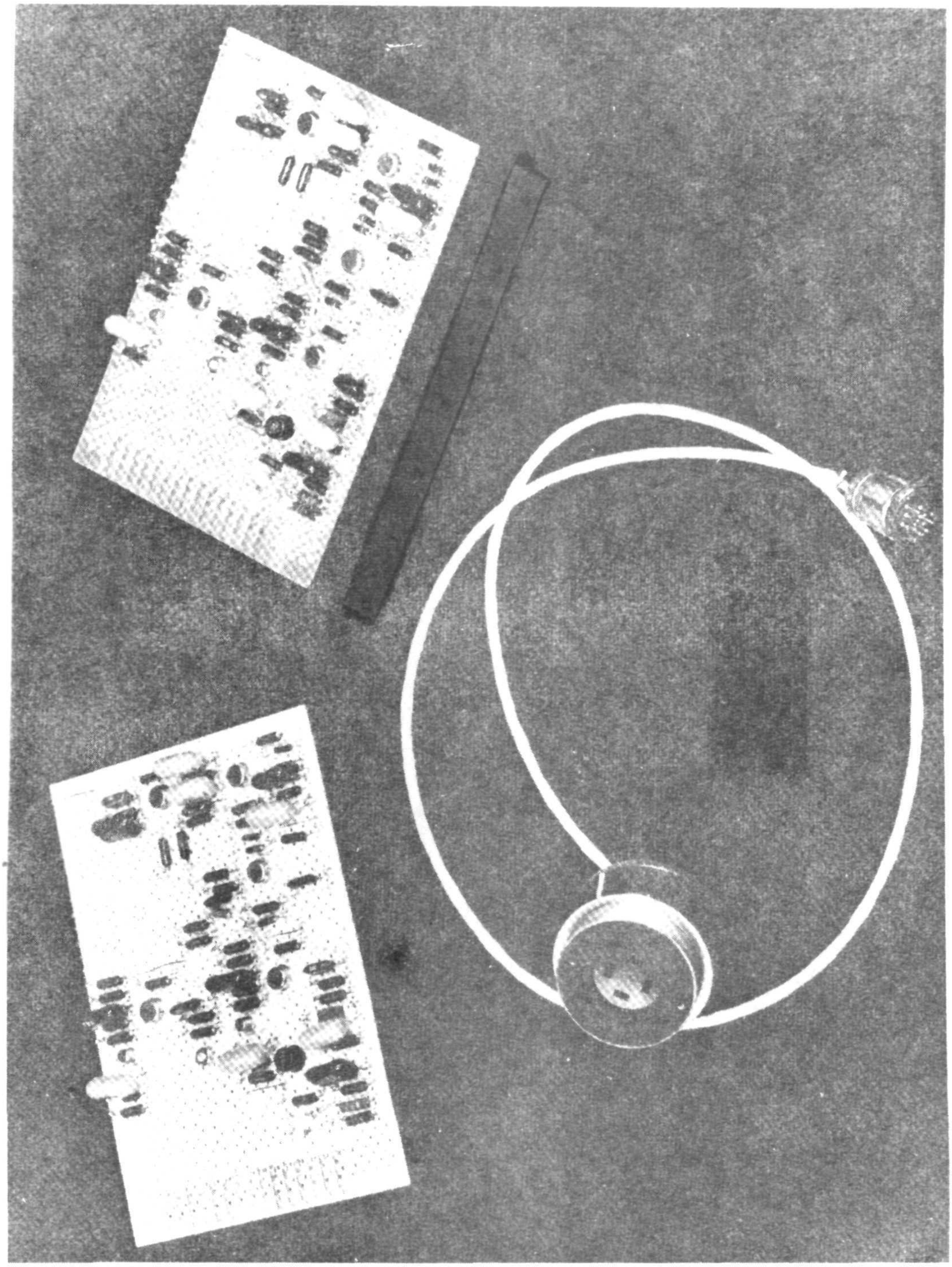

Figure 2. Sensor head and electronics.

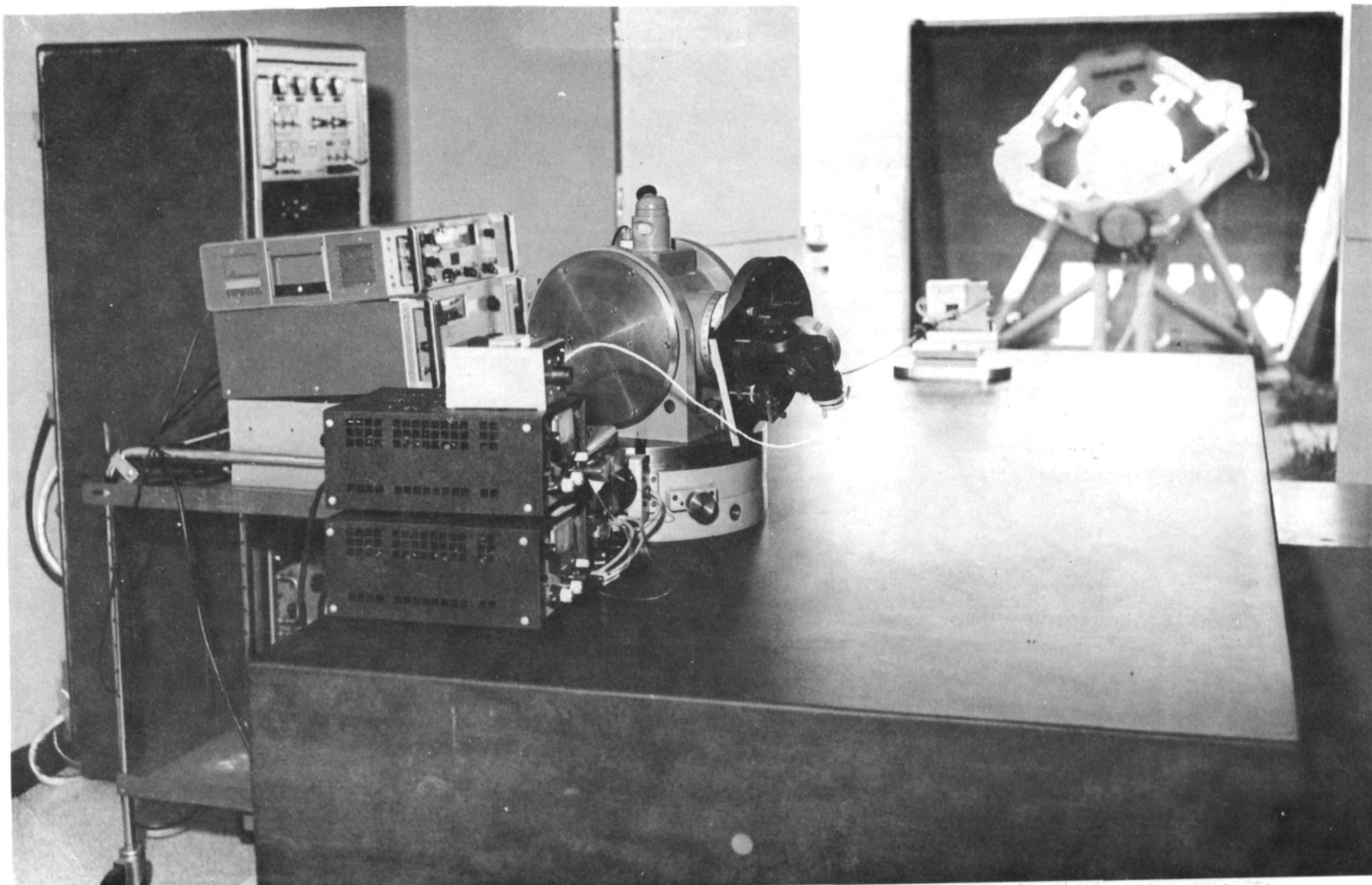

Figure 3. Test setup showing heliostat.

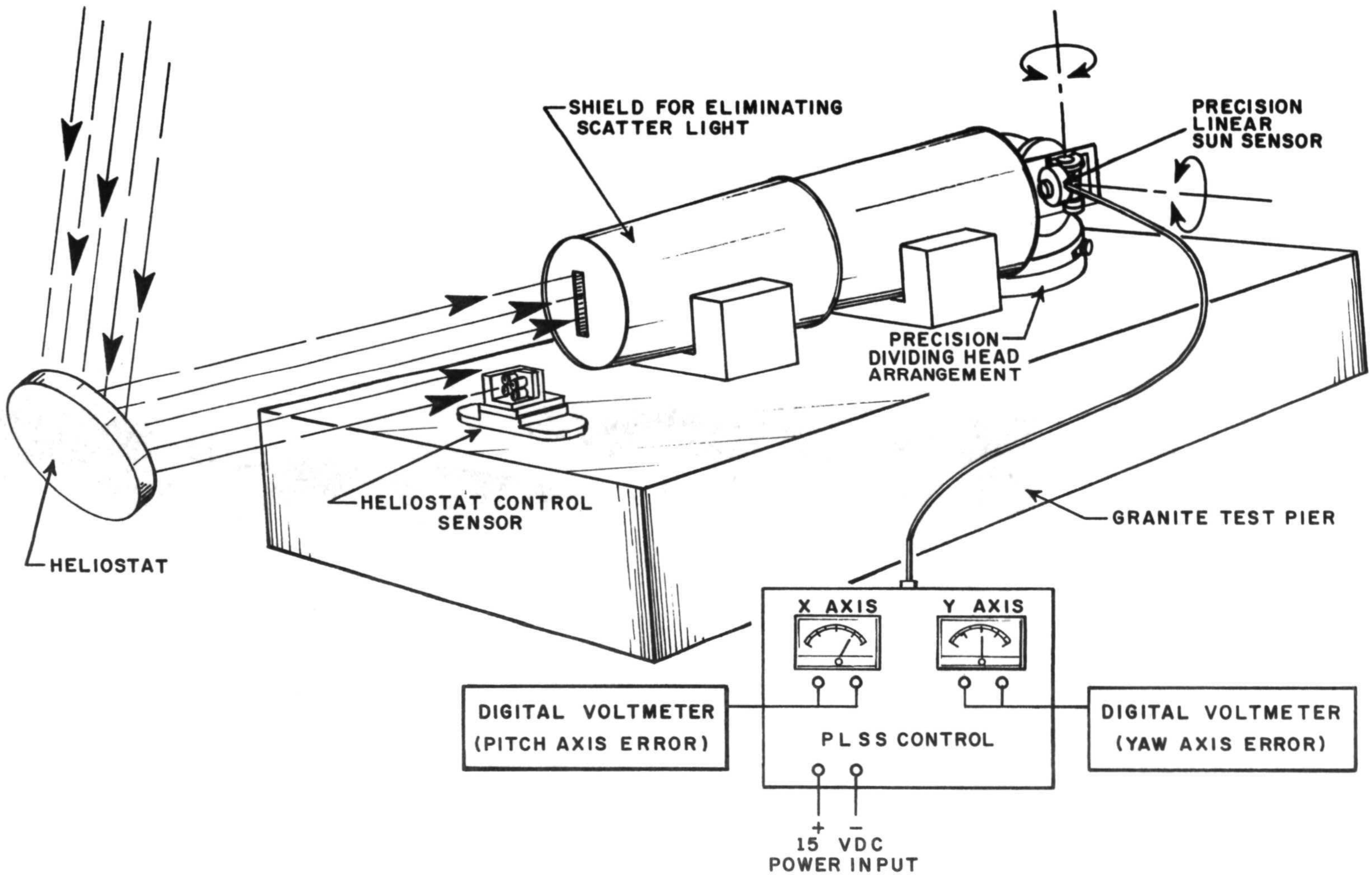


Figure 4. Precision linear sun sensor test setup utilizing heliostat for solar input.

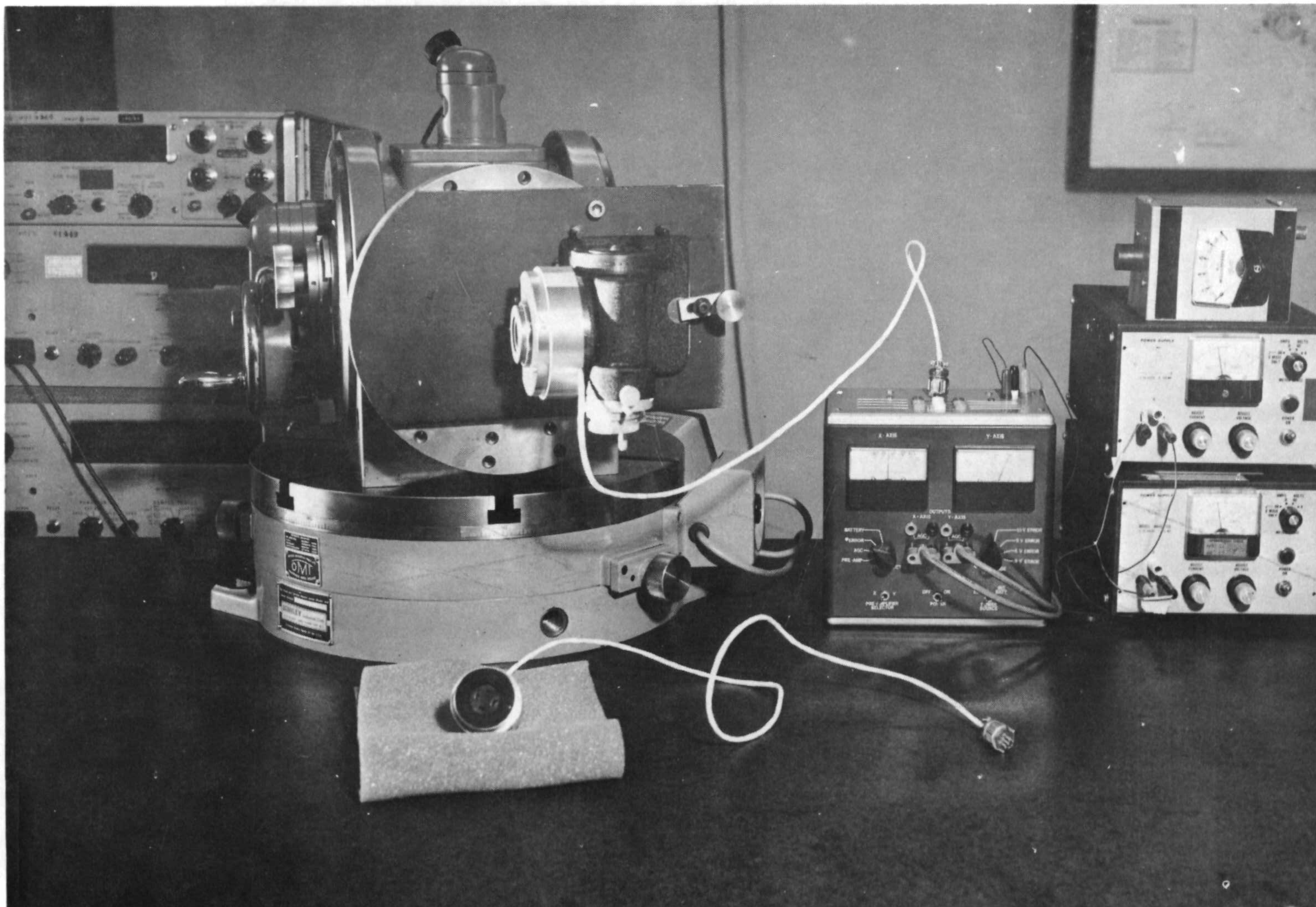

Figure 5. Dividing head arrangement, sensor, and controls.

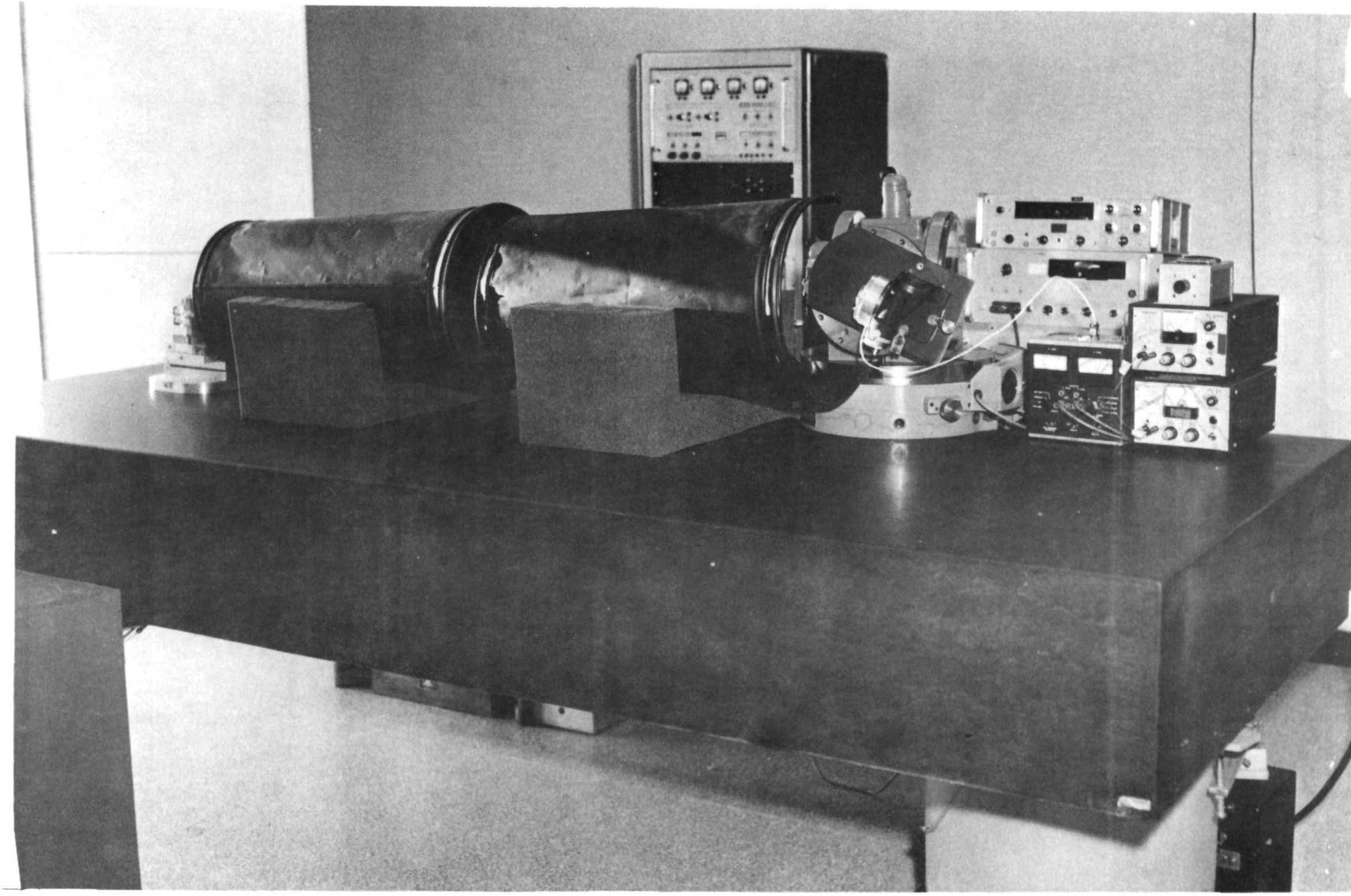

Figure 6. Test setup showing light shields.

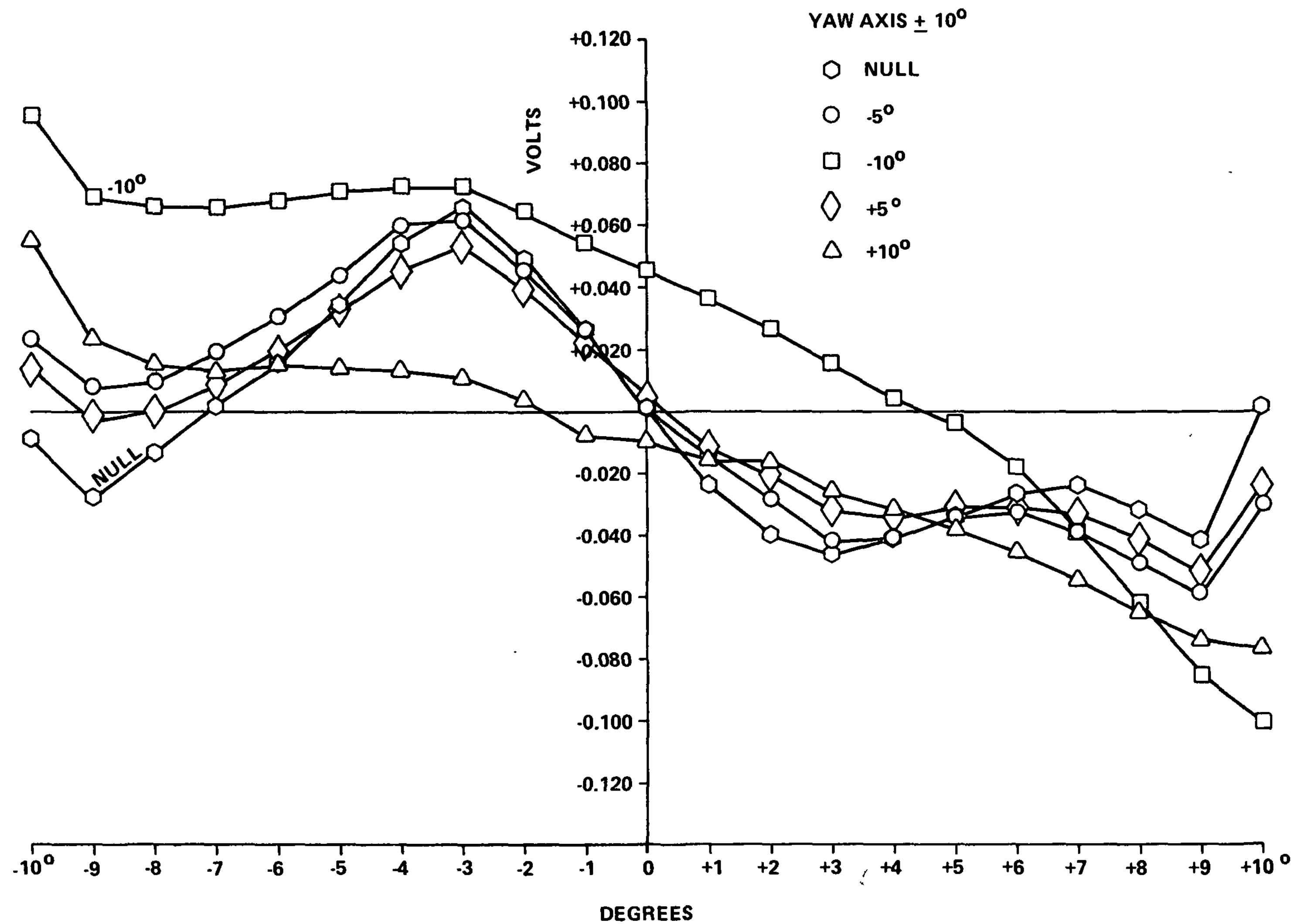


Figure 7. Ideal volts - $\frac{V_0 K}{\cos \delta}$ versus degrees (yaw axis ±10 deg FOV).

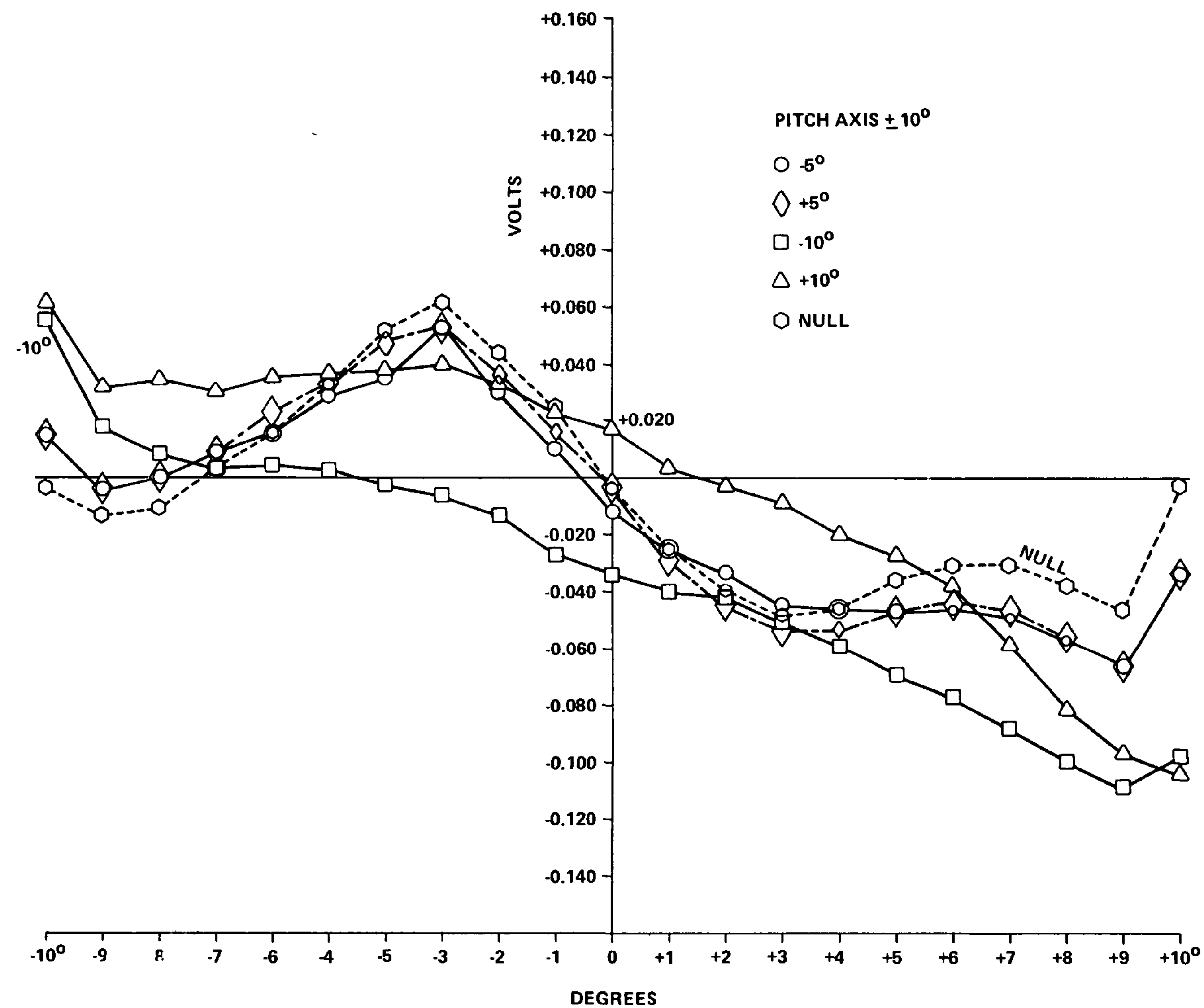


Figure 8. Ideal volts - $\frac{V_0 K}{\cos \delta}$ versus degrees (pitch axis ±10 deg FOV).

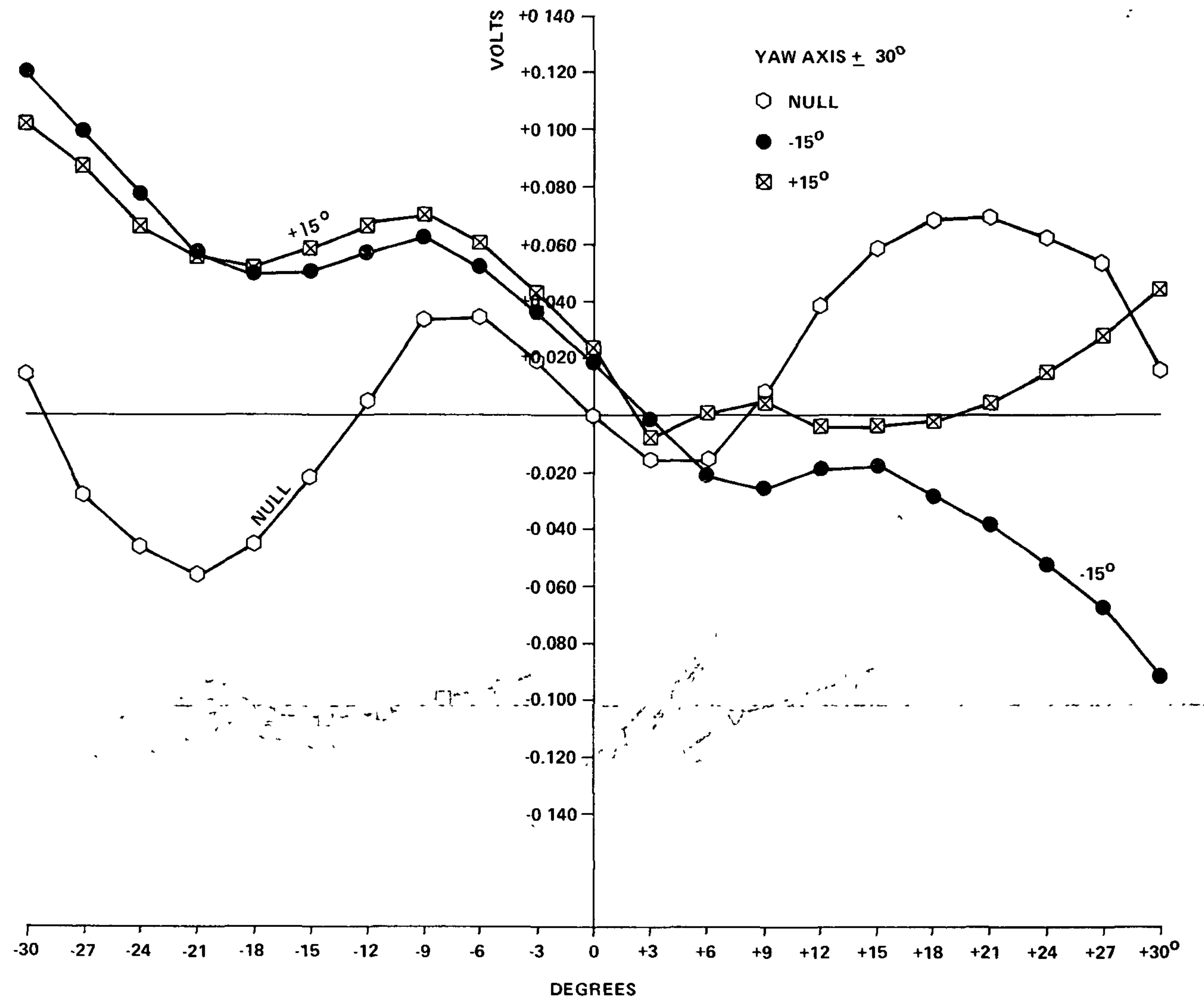


Figure 9. Ideal volts - $\frac{V_0 K}{\cos \delta}$ versus degrees (yaw axis ±30 deg FOV).

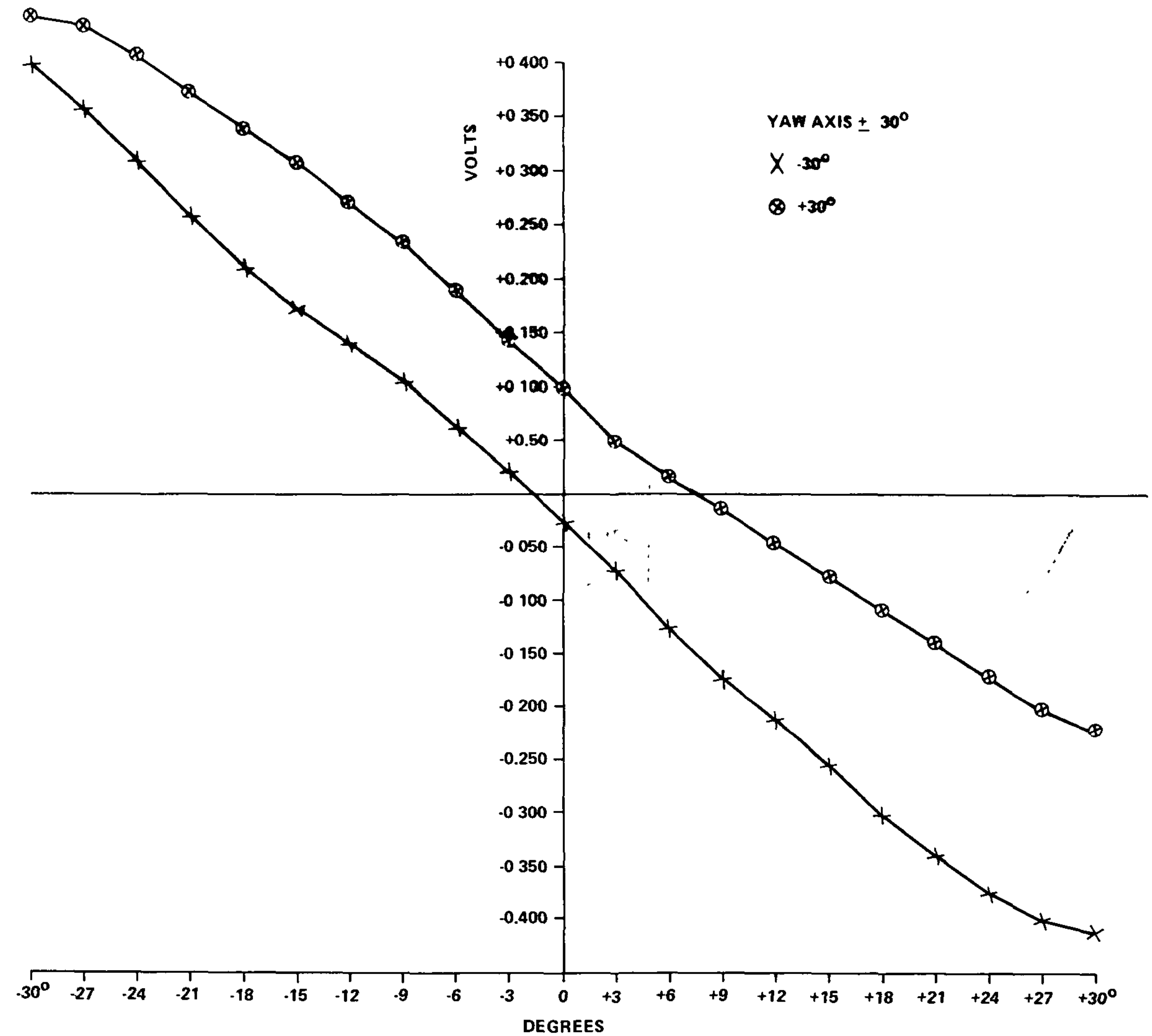


Figure 10. Ideal volts - $\frac{V_0 K}{\cos \delta}$ versus degrees (yaw axis ±30 deg FOV).

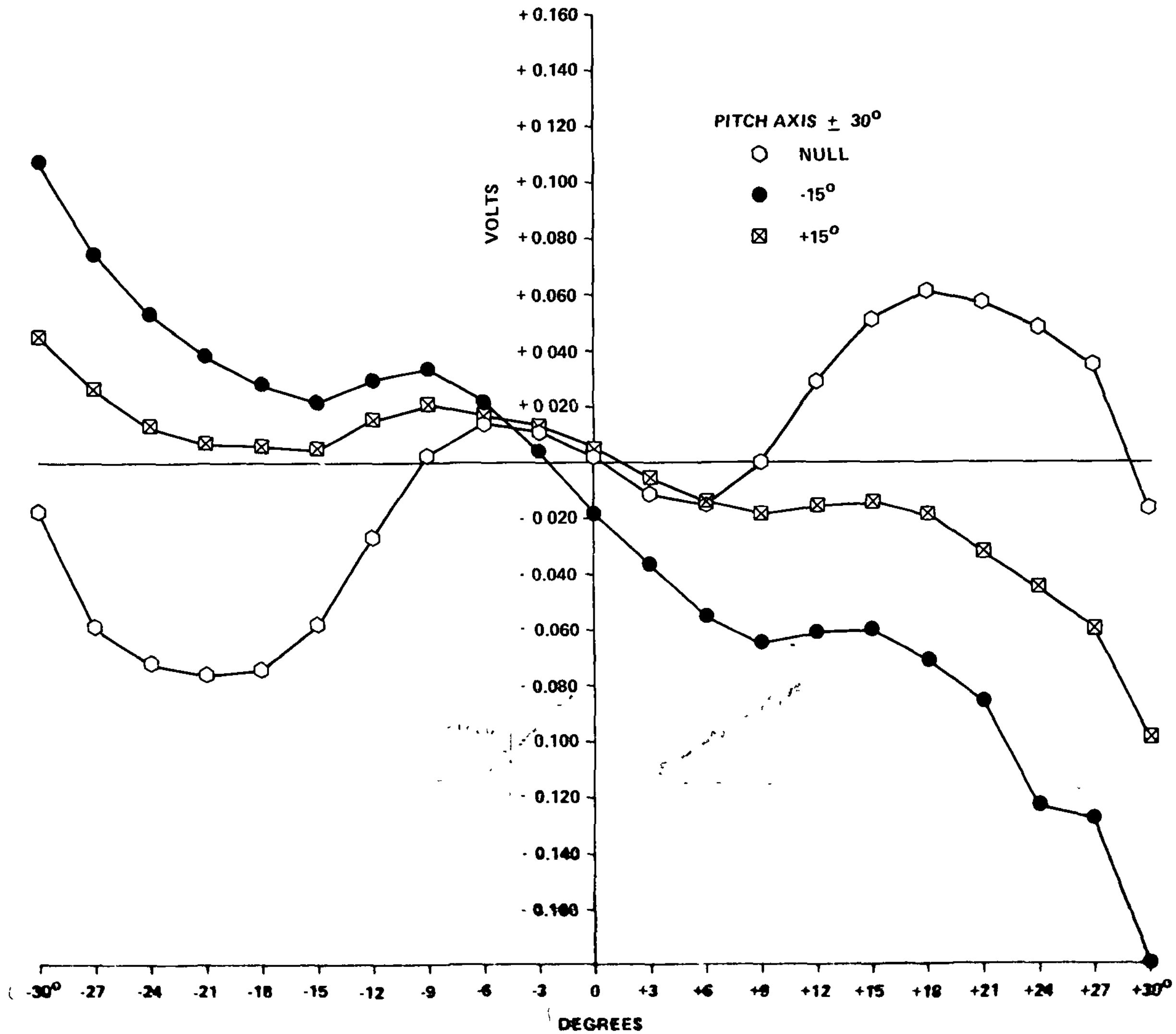


Figure 11. Ideal volts - $\frac{V_0 K}{\cos \delta}$ versus degrees (pitch axis ±30 deg FOV).

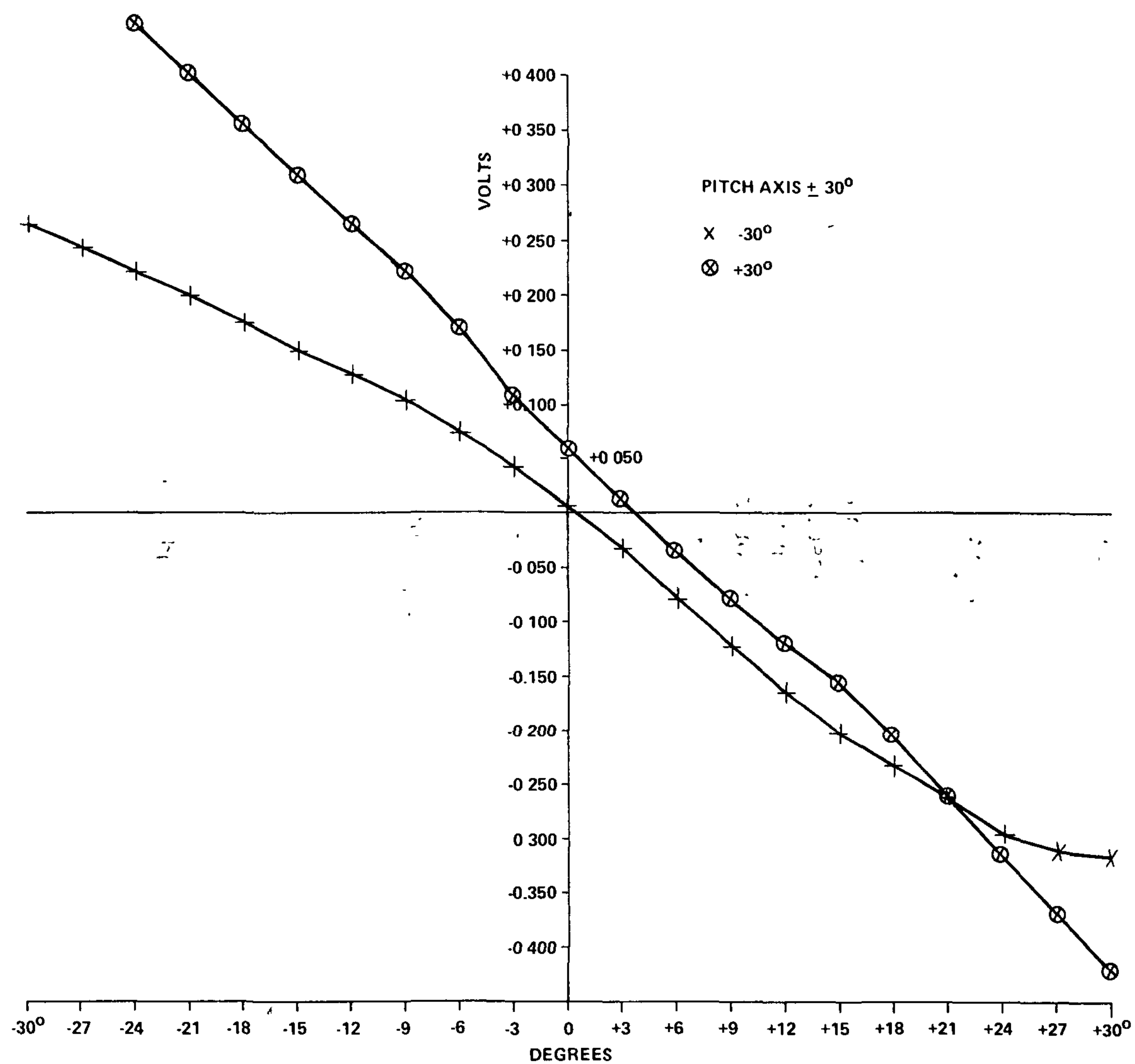


Figure 12. Ideal volts - $\frac{V_0 K}{\cos \delta}$ versus degrees (pitch axis ±30 deg FOV).

# APPENDIX A. PRECISE LINEAR SUN SENSOR DESCRIPTION*

## INTRODUCTION

The precise linear sun sensor is a system that linearly converts an angle, $\theta$, into an output voltage, $V_0$. This system can be made to operate independently of an orthogonal angle, $\phi$. Both $\theta$ and $\phi$ may vary between +30 deg and -30 deg, and $V_0$ is accurate to within 0.1 deg of $\theta$ for all values of $\theta$ and $\phi$.

## SYSTEM ANALYSIS

The PLSS system uses both geometry and an electronic divider to change the dimensions of the active area of a silicon sensor. A cross-sectional sketch is shown in Figure A-1. The entire cross section is rotated forward an angle $\phi$ about the y-axis. Two slits, of width s and of length l, are imaged on the sensors. The left sensor picks up a signal, $e_L$, per unit length:

$$e_L = I R_L (s_1 + s_2) \quad ,$$

where I is the effective illumination of the source, and $R_L$ is the left sensor responsivity.

The right sensor picks up a signal, $e_R$, per unit length:

$$e_R = I R_R x_3 \quad ,$$

where $R_R$ is the right sensor responsivity.

The total voltages, $V_L$ and $V_R$, depend on the lengths of the slits,

$$V_L = l_L e_L$$

$$V_R = l_R e_R \quad .$$

* This material was excerpted from the Honeywell-prepared literature that accompanied the system.

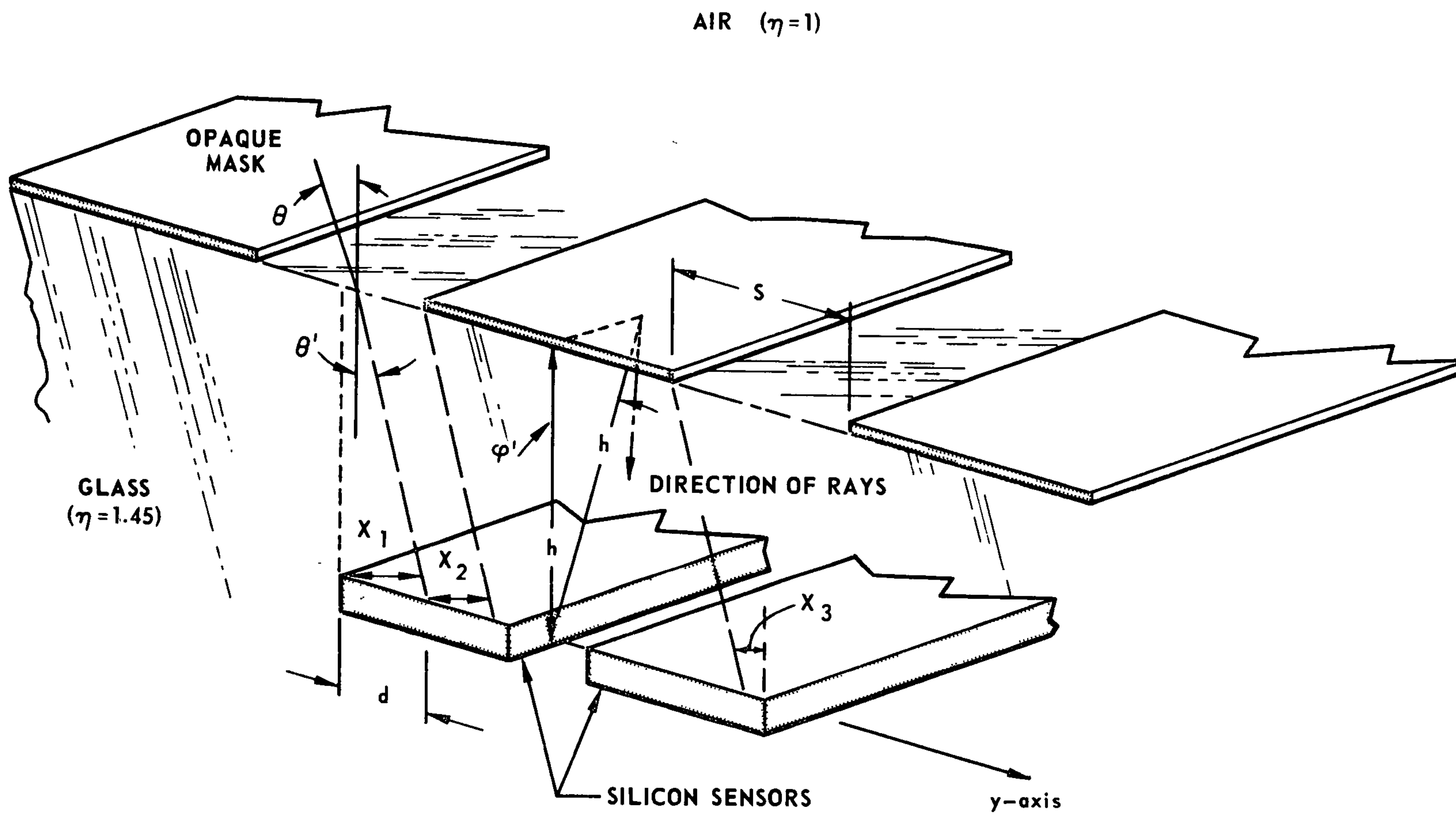


Figure A-1. Cross-sectional view of detector (incoming rays are slanted at angle $\phi$ into the paper and an angle $\theta$ to the right; total slit length is l).

The geometry is designed so that

$$x_2 + x_3 = x_1$$

or

$$x_3 = x_1 - x_2$$

For future reference, the dimensions $x_1$ and $x_2$ are

$$x_1 = d \cos \theta'$$

and

$$x_2 = \hat{h} \sin \theta' ,$$

where $\hat{h} = \dfrac{h}{\cos \phi'}$ and $\theta'$ and $\phi'$ are the counterparts in the glass of $\theta$ and $\phi$.

The system is designed to compute the output voltage as the ratio

$$V_0 = \frac{V_L - V_R}{V_L + V_R}$$

$$= \frac{\left(l_L R_L - l_R R_R\right) x_1 + \left(l_L R_L + l_R R_R\right) x_2}{\left(l_L R_L + l_R R_R\right) x_1 + \left(l_L R_L - l_R R_R\right) x_2} . \qquad (1)$$

Nominally there is complete symmetry and each L-parameter is equal to its R-parameter counterpart. Hence,

$$V_0 = \frac{x_2}{x_1} = \left(\frac{h}{d}\right)\left(\frac{\tan \theta'}{\cos \phi'}\right) .$$

In practice, however, complete symmetry may not occur. If we assume that $R_R = R - \dfrac{\Delta R}{2}$ and $R_L = R + \dfrac{\Delta R}{2}$ and that there is complete symmetry otherwise, equation (1) becomes

$$V_0 = \frac{\frac{\Delta R}{2R} + \frac{x_2}{x_1}}{1 + \frac{\Delta R}{2R}\frac{x_2}{x_1}} \approx \frac{x_2}{x_1} + \frac{\Delta R}{2R}\left[1 - \left(\frac{x_2}{x_1}\right)^2\right] \quad . \qquad (2)$$

The last statement in equation (2) results from expanding $\frac{1}{1 + x}$ in a Taylor series and then dropping terms containing $\left(\frac{\Delta R}{R}\right)^2$ or higher order. At $\theta = 0$ the nonlinear error term is $\frac{\Delta R}{2R}$ since $x_2 = 0$. As $\theta \to 30°$, $x_2 \approx x_1$ and the nonlinear term is approximately 0. This introduces a quadratic nonlinearity into the system.

If there is complete symmetry except that $l_R = l - \frac{\Delta l}{2}$ and $l_L = l + \frac{\Delta l}{2}$, by a similar analysis we see that

$$V_0 \approx \frac{x_2}{x_1} + \frac{\Delta l}{2l}\left[1 - \left(\frac{x_2}{x_1}\right)^2\right] \quad . \qquad (3)$$

Note that there is the same type quadratic nonlinearity as with a responsivity mismatch.

If the only asymmetry is $d_R = d - \frac{\Delta d}{2}$ and $d_L = d + \frac{\Delta d}{2}$, then

$$V_0 = \frac{x_2}{x_1} + \frac{\Delta d}{2d} \quad . \qquad (4)$$

Note that this is a constant offset voltage independent of both $\theta'$ and $\phi'$.

Finally if the only asymmetry is $h_R = h - \frac{\Delta h}{2}$ and $h_L = h + \frac{\Delta h}{2}$,

$$V_0 \approx \left(1 - \frac{\Delta h}{2h}\right)\frac{x_2}{x_1} \qquad (5)$$

As a first order approximation a mismatch in h changes the scale factor in the electronic output voltage.

## LINEARITY AND CROSS-COUPLING

In the previous section we saw what effect various mismatches had on the output voltage $V_0$,

$$V_0 = \frac{x_2}{x_1} = \frac{h}{d} \frac{\tan \theta'}{\cos \phi'} \tag{1a}$$

In this section we shall see how linear the $\theta$ - $V_0$ relation is. The equations governing the optics are

$$\tan^2 \theta + \tan^2 \phi = \tan^2 \psi \tag{6}$$

$$\tan^2 \theta' + \tan^2 \phi' = \tan^2 \psi' \tag{6a}$$

$$\sin \psi = \eta \sin \psi' \tag{6b}$$

and

$$\frac{\tan \theta}{\tan \phi} = \frac{\tan \theta'}{\tan \phi'} \tag{6c}$$

Equations (6) and (6a) define angles $\psi$ and $\psi'$ ; equation (6b) is Snells's law; and equation (6c) states that the tangential phase velocity is the same on both sides of the air-glass boundary.

Computer simulation and analysis shows that the best fit to $f(\theta', \phi') = \frac{\tan \theta'}{\cos \phi'}$ by $g(\theta) = K\theta$ would introduce an error of 1.0 percent or 0.30 deg. On the other hand, the best fit to f by $g(\theta, \phi) = K(\phi)\theta$ is better. Its maximum error is 0.5 percent or 0.15 deg. This shows that there is some cross-coupling between $\theta$ and $\phi$

In both cases the poorest fit to a straight line occurs at the extreme values of $\theta$ and $\phi$. Smaller fields-of-view can be represented linearly more accurately. A rough estimate of the magnitude of this nonlinearity is that it is quadratic in both $\theta'$ and $\phi'$

The nonlinearity and cross-coupling are both dependent on the index of refraction. For example, a different material $(\eta \approx 1.5 - 1.6)$ using $g(\theta, \phi) = K(\phi)\theta$ would be able to give a maximum nonlinearity of less than 0.33 percent or 0.1 deg.

Note that $K(\phi)$ can be realized by using a mask. The edge of this mask, $m(x)$, is determined by the integral equation

$$\int_{x-\frac{1}{2}}^{x+\frac{1}{2}} m(\xi)\, d\xi = w(x) = K\left[\tan^{-1}\left(\frac{x}{h}\right)\right] \tag{7}$$

It can be solved in a straightforward manner by using Fourier transform techniques. A more practical approach is to note $w(x)$ is an even function. An approximation of the form

$$w(x) = A + Bx^2 + Cx^4 \tag{7a}$$

is quite reasonable. An approximation for $m(x)$ of the form

$$m(x) = a + bx^2 + cx^4 \tag{7b}$$

leads to a simple and satisfactory solution to equation (7). The relations between the coefficients are

$$C = lc \tag{7c}$$

$$B = l\left(b + c\,\frac{l^2}{2}\right) \tag{7d}$$

and

$$A = l\left(a + b\,\frac{l^2}{12} + c\,\frac{l^4}{80}\right) \tag{7e}$$

# APPENDIX B. TEST DATA FOR EVALUATION OF PLSS

Data Date: November 17, 1971 Test Engr.: D. D. Johnston

PLSS: ±10 deg Head Yaw Axis

| Command Angle, deg | Volts for Ideal S. F.* 0.33333 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ ** | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| -10 | -10.000 | -9.940 | 1.022 | -10.056 | +0.056 |
| - 9 | - 9.000 | -8.918 | 0.996 | - 9.023 | +0.023 |
| - 8 | - 8.000 | -7.922 | 0.990 | - 8.015 | +0.015 |
| - 7 | - 7.000 | -6.932 | 0.987 | - 7.013 | +0.013 |
| - 6 | - 6.000 | -5.945 | 0.989 | - 6.015 | +0.015 |
| - 5 | - 5.000 | -4.956 | 0.989 | - 5.014 | +0.014 |
| - 4 | - 4.000 | -3.967 | 0.991 | - 4.013 | +0.013 |
| - 3 | - 3.000 | -2.976 | 0.995 | - 3.011 | +0.011 |
| - 2 | - 2.000 | -1.981 | 1.000 | - 2.004 | +0.004 |
| - 1 | - 1.000 | -0.981 | 0.991 | - 0.992 | -0.008 |
| NULL | 0.000 | +0.010 | | + 0.010 | -0.010 |
| + 1 | + 1.000 | +1.004 | 0.994 | + 1.016 | -0.016 |
| + 2 | + 2.000 | +1.993 | 0.989 | + 2.016 | -0.016 |
| + 3 | + 3.000 | +2.991 | 0.998 | + 3.026 | -0.026 |
| + 4 | + 4.000 | +3.985 | 0.994 | + 4.032 | -0.032 |
| + 5 | + 5.000 | +4.980 | 0.995 | + 5.038 | -0.038 |
| + 6 | + 6.000 | +5.975 | 0.995 | + 6.045 | -0.045 |
| + 7 | + 7.000 | +6.973 | 0.998 | + 7.055 | -0.055 |
| + 8 | + 8.000 | +7.972 | 0.999 | + 8.065 | -0.065 |
| + 9 | + 9.000 | +8.969 | 0.997 | + 9.074 | -0.074 |
| +10 | +10.000 | +9.960 | 0.991 | +10.077 | -0.077 |

*Scale factor
**K is constant

Pitch (Nonsensitive) Axis Output Voltage: +9.724

OMT Reading: 299 deg 12 min 49 s Solar Constant: 49 percent

Angle: +10 deg Mask Used: Yes

Data Date: November 17, 1971 | Test Engr.: D. D. Johnston

PLSS: ±10 deg Head | Yaw Axis

| Command Angle, deg | Volts for Ideal S. F. 1.000 V | Direct Volts ( $V_0$ ) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| -10 | -10.000 | -10.012 | 1.017 | -10.014 | +0.014 |
| - 9 | - 9.000 | - 8.995 | 0.996 | - 8.997 | -0.003 |
| - 8 | - 8.000 | - 7.999 | 0.992 | - 8.000 | 0.000 |
| - 7 | - 7.000 | - 7.007 | 0.989 | - 7.008 | +0.008 |
| - 6 | - 6.000 | - 6.018 | 0.986 | - 6.019 | -0.019 |
| - 5 | - 5.000 | - 5.032 | 0.988 | - 5.033 | +0.033 |
| - 4 | - 4.000 | - 4.044 | 0.992 | - 4.045 | +0.045 |
| - 3 | - 3.000 | - 3.052 | 1.013 | - 3.053 | +0.053 |
| - 2 | - 2.000 | - 2.039 | 1.018 | - 2.039 | +0.039 |
| - 1 | - 1.000 | - 1.021 | 1.016 | - 1.021 | +0.021 |
| NULL | 0.000 | - 0.005 | | - 0.005 | +0.005 |
| + 1 | + 1.000 | + 1.012 | 1.017 | + 1.012 | -0.012 |
| + 2 | + 2.000 | + 2.021 | 1.009 | + 2.021 | -0.021 |
| + 3 | + 3.000 | + 3.031 | 1.010 | + 3.032 | -0.032 |
| + 4 | + 4.000 | + 4.033 | 1.002 | + 4.034 | -0.034 |
| + 5 | + 5.000 | + 5.032 | 0.999 | + 5.033 | -0.033 |
| + 6 | + 6.000 | + 6.030 | 0.998 | + 6.031 | -0.031 |
| + 7 | + 7.000 | + 7.032 | 1.002 | + 7.033 | -0.033 |
| + 8 | + 8.000 | + 8.041 | 1.009 | + 8.042 | -0.042 |
| + 9 | + 9.000 | + 9.050 | 1.009 | + 9.052 | -0.052 |
| +10 | +10.000 | +10.022 | 0.972 | +10.024 | -0.024 |

Pitch (Nonsensitive) Axis | Output Voltage: +4.884

OMT Reading: 304 deg 12 min 49 s | Solar Constant: 49 percent

Angle: +5 deg | Mask Used: Yes

Data Date: November 17, 1971 — Test Engr.: D. D. Johnston

PLSS: ±10 deg Head — Yaw Axis

| Command Angle, deg | Volts for Ideal S. F. 1.000 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| -10 | -10.000 | -10.027 | 1.012 | -9.991 | -0.009 |
| - 9 | - 9.000 | - 9.015 | 0.999 | -8.982 | -0.018 |
| - 8 | - 8.000 | - 8.016 | 0.998 | -7.987 | -0.013 |
| - 7 | - 7.000 | - 7.028 | 0.991 | -7.002 | +0.002 |
| - 6 | - 6.000 | - 6.037 | 0.985 | -6.015 | +0.015 |
| - 5 | - 5.000 | - 5.052 | 0.983 | -5.034 | +0.034 |
| - 4 | - 4.000 | - 4.069 | 0.992 | -4.054 | +0.054 |
| - 3 | - 3.000 | - 3.077 | 1.021 | -3.066 | +0.066 |
| - 2 | - 2.000 | - 2.056 | 1.026 | -2.049 | +0.049 |
| - 1 | - 1.000 | - 1.030 | 1.029 | -1.026 | +0.026 |
| NULL | 0.000 | - 0.001 | | -0.001 | +0.001 |
| + 1 | + 1.000 | + 1.028 | 1.029 | +1.024 | -0.024 |
| + 2 | + 2.000 | + 2.047 | 1.019 | +2.040 | -0.040 |
| + 3 | + 3.000 | + 3.058 | 1.011 | +3.047 | -0.047 |
| + 4 | + 4.000 | + 4.056 | 0.998 | +4.041 | -0.041 |
| + 5 | + 5.000 | + 5.052 | 0.996 | +5.034 | -0.034 |
| + 6 | + 6.000 | + 6.049 | 0.997 | +6.027 | -0.027 |
| + 7 | + 7.000 | + 7.050 | 1.001 | +7.024 | -0.024 |
| + 8 | + 8.000 | + 8.061 | 1.011 | +8.032 | -0.032 |
| + 9 | + 9.000 | + 9.075 | 1.014 | -9.042 | -0.042 |
| +10 | +10.000 | -10.036 | 0.961 | -9.999 | +0.001 |

Pitch (Nonsensitive) Axis — Output Voltage: ±0.001

OMT Reading: 309 deg 12 min 49 s — Solar Constant: 51 percent

Angle: Null — Mask Used: Yes

Data Date: November 17, 1971 Test Engr.: D. D. Johnston

PLSS: ±10 deg Head Yaw Axis

| Command Angle, deg | Volts for Ideal S. F. 1.000 V | Direct Volts ($V_0$) | $\Delta$ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| -10 | -10.000 | -10.021 | 1.015 | -10.023 | +0.023 |
| - 9 | - 9.000 | - 9.006 | 0.997 | - 9.008 | +0.008 |
| - 8 | - 8.000 | - 8.009 | 0.991 | - 8.010 | +0.010 |
| - 7 | - 7.000 | - 7.018 | 0.989 | - 7.019 | +0.019 |
| - 6 | - 6.000 | - 6.029 | 0.986 | - 6.030 | +0.030 |
| - 5 | - 5.000 | - 5.043 | 0.984 | - 5.044 | +0.044 |
| - 4 | - 4.000 | - 4.059 | 0.998 | - 4.060 | +0.060 |
| - 3 | - 3.000 | - 3.061 | 1.015 | - 3.062 | +0.062 |
| - 2 | - 2.000 | - 2.046 | 1.021 | - 2.046 | +0.046 |
| - 1 | - 1.000 | - 1.025 | 1.024 | - 1.025 | +0.025 |
| NULL | 0.000 | - 0.001 | | - 0.001 | +0.001 |
| + 1 | + 1.000 | + 1.015 | 1.016 | + 1.015 | -0.015 |
| + 2 | + 2.000 | + 2.028 | 1.013 | + 2.028 | -0.028 |
| + 3 | + 3.000 | + 3.041 | 1.013 | + 3.042 | -0.042 |
| + 4 | + 4.000 | + 4.040 | 0.999 | + 4.041 | -0.041 |
| + 5 | + 5.000 | + 5.034 | 0.994 | + 5.035 | -0.035 |
| + 6 | + 6.000 | + 6.031 | 0.997 | + 6.032 | -0.032 |
| + 7 | + 7.000 | + 7.038 | 1.007 | + 7.039 | -0.039 |
| + 8 | + 8.000 | + 8.048 | 1.010 | + 8.049 | -0.049 |
| + 9 | + 9.000 | + 9.057 | 1.009 | + 9.059 | -0.059 |
| +10 | +10.000 | +10.028 | 0.971 | +10.030 | -0.030 |

Pitch (Nonsensitive) Axis Output Voltage: -4.873

OMT Reading: 314 deg 12 min 49 s Solar Constant: 51 percent

Angle: -5 deg Mask Used: Yes

Data Date: November 17, 1971 Test Engr.: D. D. Johnston

PLSS: ±10 deg Head Yaw Axis

| Command Angle, deg | Volts for Ideal S. F. 1.000 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| -10 | -10.000 | -9.979 | 1.015 | -10.096 | +0.096 |
| - 9 | - 9.000 | -8.964 | 0.991 | - 9.069 | +0.069 |
| - 8 | - 8.000 | -7.973 | 0.989 | - 8.066 | +0.066 |
| - 7 | - 7.000 | -6.984 | 0.986 | - 7.066 | +0.066 |
| - 6 | - 6.000 | -5.998 | 0.986 | - 6.068 | +0.068 |
| - 5 | - 5.000 | -5.012 | 0.987 | - 5.071 | +0.071 |
| - 4 | - 4.000 | -4.025 | 0.989 | - 4.072 | +0.072 |
| - 3 | - 3.000 | -3.036 | 0.996 | - 3.072 | +0.072 |
| - 2 | - 2.000 | -2.040 | 0.998 | - 2.064 | +0.064 |
| - 1 | - 1.000 | -1.042 | 0.998 | - 1.054 | +0.054 |
| NULL | 0.000 | -0.044 | | - 0.045 | +0.045 |
| + 1 | + 1.000 | +0.953 | 0.997 | + 0.964 | +0.036 |
| + 2 | + 2.000 | +1.951 | 0.998 | + 1.974 | +0.026 |
| + 3 | + 3.000 | +2.950 | 0.999 | + 2.985 | +0.015 |
| + 4 | + 4.000 | +3.950 | 1.000 | + 3.996 | +0.004 |
| + 5 | + 5.000 | +4.946 | 0.996 | + 5.004 | -0.004 |
| + 6 | + 6.000 | +5.948 | 1.002 | + 6.018 | -0.018 |
| + 7 | + 7.000 | +6.957 | 1.009 | + 7.038 | -0.038 |
| + 8 | + 8.000 | +7.969 | 1.012 | + 8.062 | -0.062 |
| + 9 | + 9.000 | +8.980 | 1.011 | + 9.085 | -0.085 |
| +10 | +10.000 | +9.984 | 1.004 | +10.101 | -0.101 |

Pitch (Nonsensitive) Axis Output Voltage: -9.576

OMT Reading: 319 deg 12 min 49 s Solar Constant: 50 percent

Angle: -10 deg Mask Used: Yes

Data Date: November 10, 1971 | Test Engr.: D. D. Johnston

PLSS: ±10 deg Head | Pitch Axis

| Command Angle, deg | Volts for Ideal S. F. 1.000 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| +10 | +10.000 | +9.980 | 0.995 | +10.104 | -0.104 |
| + 9 | + 9.000 | +8.985 | 1.004 | + 9.097 | -0.097 |
| + 8 | + 8.000 | +7.981 | 1.009 | + 8.081 | -0.081 |
| + 7 | + 7.000 | +6.972 | 1.008 | + 7.059 | -0.059 |
| + 6 | + 6.000 | +5.964 | 0.999 | + 6.038 | -0.038 |
| + 5 | + 5.000 | +4.965 | 0.995 | + 5.027 | -0.027 |
| + 4 | + 4.000 | +3.970 | 0.998 | + 4.020 | -0.020 |
| + 3 | + 3.000 | +2.972 | 0.994 | + 3.009 | -0.009 |
| + 2 | + 2.000 | +1.978 | 0.993 | + 2.003 | -0.003 |
| + 1 | + 1.000 | +0.985 | 1.002 | + 0.997 | +0.003 |
| NULL | 0.000 | -0.017 | | - 0.017 | +0.017 |
| - 1 | - 1.000 | -1.009 | 0.992 | - 1.022 | +0.022 |
| - 2 | - 2.000 | -2.008 | 0.999 | - 2.033 | +0.033 |
| - 3 | - 3.000 | -3.003 | 0.995 | - 3.040 | +0.040 |
| - 4 | - 4.000 | -3.988 | 0.985 | - 4.038 | +0.038 |
| - 5 | - 5.000 | -4.975 | 0.987 | - 5.037 | +0.037 |
| - 6 | - 6.000 | -5.962 | 0.987 | - 6.036 | +0.036 |
| - 7 | - 7.000 | -6.943 | 0.981 | - 7.030 | +0.030 |
| - 8 | - 8.000 | -7.936 | 0.993 | - 8.035 | +0.035 |
| - 9 | - 9.000 | -8.921 | 0.985 | - 9.032 | +0.032 |
| -10 | -10.000 | -9.938 | 1.017 | -10.062 | +0.062 |

Yaw (Nonsensitive Axis) | Output Voltage: +9.562

OMT Reading: 351 deg 6 min 24 s | Solar Constant: 52 percent

Angle: +10 deg | Mask Used: No

Data Date: November 10, 1971 Test Engr.: D. D. Johnston

PLSS: ±10 deg Head Pitch Axis

| Command Angle, deg | Volts for Ideal S. F. 1.0000 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| +10 | +10.000 | +10.024 | 0.967 | +10.033 | -0.033 |
| + 9 | + 9.000 | + 9.057 | 1.007 | + 9.065 | -0.065 |
| + 8 | + 8.000 | + 8.050 | 1.009 | + 8.057 | -0.057 |
| + 7 | + 7.000 | + 7.041 | 1.002 | + 7.047 | -0.047 |
| + 6 | + 6.000 | + 6.039 | 0.997 | + 6.044 | -0.044 |
| + 5 | + 5.000 | + 5.042 | 0.992 | + 5.047 | -0.047 |
| + 4 | + 4.000 | + 4.050 | 0.999 | + 4.054 | -0.054 |
| + 3 | + 3.000 | + 3.051 | 1.008 | + 3.054 | -0.054 |
| + 2 | + 2.000 | + 2.043 | 1.015 | + 2.045 | -0.045 |
| + 1 | + 1.000 | + 1.028 | 1.025 | + 1.029 | -0.029 |
| NULL | 0.000 | + 0.003 | | + 0.003 | -0.003 |
| - 1 | - 1.000 | - 1.014 | 1.017 | - 1.015 | +0.015 |
| - 2 | - 2.000 | - 2.034 | 1.020 | - 2.036 | +0.036 |
| - 3 | - 3.000 | - 3.051 | 1.017 | - 3.054 | +0.054 |
| - 4 | - 4.000 | - 4.045 | 0.994 | - 4.049 | +0.049 |
| - 5 | - 5.000 | - 5.029 | 0.984 | - 5.034 | +0.034 |
| - 6 | - 6.000 | - 6.018 | 0.989 | - 6.023 | +0.023 |
| - 7 | - 7.000 | - 7.002 | 0.984 | - 7.008 | +0.008 |
| - 8 | - 8.000 | - 7.993 | 0.991 | - 8.000 | +0.000 |
| - 9 | - 7.000 | - 8.988 | 0.995 | - 8.996 | -0.004 |
| -10 | -10.000 | -10.006 | 1.018 | -10.015 | +0.015 |

Yaw (Nonsensitive) Axis

OMT Reading: 356 deg 6 min 24 s

Angle: +5 deg

Output Voltage: 4.780

Solar Constant: 52 percent

Mask Used: No

Data Date: November 10, 1971 Test Engr.: D. D. Johnston

PLSS: ±10 deg Head Pitch Axis

| Command Angle, deg | Volts for Ideal S. F. 1.000 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| +10 | +10.000 | +10.032 | 0.959 | +10.003 | -0.003 |
| + 9 | + 9.000 | + 9.073 | 1.012 | + 9.041 | -0.047 |
| + 8 | + 8.000 | + 8.061 | 1.010 | + 8.038 | -0.038 |
| + 7 | + 7.000 | + 7.051 | 1.002 | + 7.031 | -0.031 |
| + 6 | + 6.000 | + 6.049 | 0.998 | + 6.031 | -0.031 |
| + 5 | + 5.000 | + 5.051 | 0.993 | + 5.036 | -0.036 |
| + 4 | + 4.000 | + 4.058 | 1.001 | + 4.046 | -0.046 |
| + 3 | + 3.000 | + 3.051 | 1.011 | + 3.048 | -0.048 |
| + 2 | + 2.000 | + 2.046 | 1.018 | + 2.040 | -0.040 |
| + 1 | + 1.000 | + 1.028 | 1.024 | + 1.025 | -0.025 |
| NULL | 0.000 | + 0.004 | | + 0.004 | -0.004 |
| - 1 | - 1.000 | - 1.027 | 1.031 | - 1.024 | +0.024 |
| - 2 | - 2.000 | - 2.050 | 1.023 | - 2.044 | +0.044 |
| - 3 | - 3.000 | - 3.071 | 1.021 | - 3.062 | +0.062 |
| - 4 | - 4.000 | - 4.064 | 0.993 | - 4.052 | +0.052 |
| - 5 | - 5.000 | - 5.048 | 0.984 | - 5.033 | +0.033 |
| - 6 | - 6.000 | - 6.035 | 0.987 | - 6.017 | +0.017 |
| - 7 | - 7.000 | - 7.025 | 0.990 | - 7.005 | -0.005 |
| - 8 | - 8.000 | - 8.013 | 0.988 | - 7.990 | -0.010 |
| - 9 | - 9.000 | - 9.013 | 1.000 | - 8.981 | -0.013 |
| -10 | -10.000 | -10.026 | 1.013 | - 9.997 | -0.003 |

Yaw (Nonsensitive) Axis Output Voltage: -0.016

OMT Reading: 1 deg 6 min 24 s Solar Constant: 52 percent

Angle: Null Mask Used: No

Data Date: November 10, 1971 | Test Engr.: D. D. Johnston

PLSS: ±10 deg Head | Pitch Axis

| Command Angle, deg | Volts for Ideal S. F. 1.000 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| +10 | +10.000 | +10.025 | 0.967 | +10.034 | -0.034 |
| + 9 | + 9.000 | + 9.058 | 1.008 | + 9.066 | -0.066 |
| + 8 | + 8.000 | + 8.050 | 1.007 | + 8.057 | -0.057 |
| + 7 | + 7.000 | + 7.043 | 1.002 | + 7.049 | -0.049 |
| + 6 | + 6.000 | + 6.041 | 0.999 | + 6.046 | -0.046 |
| + 5 | + 5.000 | + 5.042 | 1.000 | + 5.047 | -0.047 |
| + 4 | + 4.000 | + 4.042 | 1.000 | + 4.046 | -0.046 |
| + 3 | + 3.000 | + 3.042 | 1.011 | + 3.045 | -0.045 |
| + 2 | + 2.000 | + 2.031 | 1.007 | + 2.033 | -0.033 |
| + 1 | + 1.000 | + 1.024 | 1.012 | + 1.025 | -0.025 |
| NULL | 0.000 | + 0.012 | | + 0.012 | -0.012 |
| - 1 | - 1.000 | - 1.009 | 1.021 | - 1.010 | +0.010 |
| - 2 | - 2.000 | - 2.028 | 1.019 | - 2.030 | +0.030 |
| - 3 | - 3.000 | - 3.038 | 1.010 | - 3.053 | +0.053 |
| - 4 | - 4.000 | - 4.032 | 0.994 | - 4.036 | +0.036 |
| - 5 | - 5.000 | - 5.024 | 0.992 | - 5.029 | +0.029 |
| - 6 | - 6.000 | - 6.011 | 0.987 | - 6.016 | +0.016 |
| - 7 | - 7.000 | - 7.003 | 0.992 | - 7.009 | +0.009 |
| - 8 | - 8.000 | - 7.993 | 0.990 | - 8.000 | +0.000 |
| - 9 | - 9.000 | - 8.988 | 0.995 | - 8.996 | -0.004 |
| -10 | -10.000 | -10.006 | 1.018 | -10.015 | +0.015 |

Yaw (Nonsensitive) Axis | Output Voltage: -4.923

OMT Reading: 6 deg 6 min 24 s | Solar Constant: 52 percent

Angle: -5 deg | Mask Used: No

Data Date: November 10, 1971 Test Engr.: D. D. Johnston

PLSS: ±10 deg Head Pitch Axis

| Command Angle, deg | Volts for Ideal S. F. 1.000 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| +10 | -10.000 | +9.974 | 0.977 | +10.098 | -0.098 |
| + 9 | + 9.000 | +8.997 | 0.991 | + 9.109 | -0.109 |
| + 8 | + 8.000 | +8.000 | 0.999 | + 8.100 | -0.100 |
| + 7 | + 7.000 | +7.001 | 0.999 | + 7.088 | -0.088 |
| + 6 | + 6.000 | +6.002 | 0.995 | + 6.077 | -0.077 |
| + 5 | + 5.000 | +5.007 | 0.998 | + 5.069 | -0.069 |
| + 4 | + 4.000 | +4.009 | 0.996 | + 4.059 | -0.059 |
| + 3 | + 3.000 | +3.013 | 0.996 | + 3.051 | -0.051 |
| + 2 | + 2.000 | +2.017 | 0.990 | + 2.042 | -0.042 |
| + 1 | + 1.000 | +1.027 | 0.993 | + 1.040 | -0.040 |
| NULL | 0.000 | +0.034 | | + 0.034 | -0.034 |
| - 1 | - 1.000 | -0.961 | 0.995 | - 0.973 | -0.027 |
| - 2 | - 2.000 | -1.963 | 1.002 | - 1.987 | -0.013 |
| - 3 | - 3.000 | -2.957 | 0.994 | - 2.994 | -0.006 |
| - 4 | - 4.000 | -3.949 | 0.992 | - 3.998 | -0.002 |
| - 5 | - 5.000 | -4.941 | 0.992 | - 5.003 | +0.003 |
| - 6 | - 6.000 | -5.931 | 0.990 | - 6.005 | +0.005 |
| - 7 | - 7.000 | -6.918 | 0.987 | - 7.004 | +0.004 |
| - 8 | - 8.000 | -7.910 | 0.992 | - 8.009 | +0.009 |
| - 9 | - 9.000 | -8.907 | 0.997 | - 9.018 | +0.018 |
| -10 | -10.000 | -9.933 | 1.026 | -10.057 | +0.057 |

Yaw (Nonsensitive) Axis Output Voltage: -9.712

OMT Reading: 11 deg 6 min 24 s Solar Constant: 52 percent

Angle: -10 deg Mask Used: No

Data Date: November 15, 1971 Test Engr.: D. D. Johnston

PLSS: ±30 deg Head Yaw Axis

| Command Angle, deg | Volts for Ideal S. F. 0.33333 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| -30 | -10.000 | -9.070 | 0.876 | -10.442 | +0.442 |
| -27 | - 9.000 | -8.194 | 0.892 | - 9.434 | +0.434 |
| -24 | - 8.000 | -7.302 | 0.898 | - 8.407 | +0.407 |
| -21 | - 7.000 | -6.404 | 0.898 | - 7.373 | +0.373 |
| -18 | - 6.000 | -5.506 | 0.898 | - 6.339 | +0.339 |
| -15 | - 5.000 | -4.610 | 0.896 | - 5.307 | +0.307 |
| -12 | - 4.000 | -3.709 | 0.901 | - 4.270 | +0.270 |
| - 9 | - 3.000 | -2.808 | 0.901 | - 3.233 | +0.233 |
| - 6 | - 2.000 | -1.900 | 0.908 | - 2.187 | +0.187 |
| - 3 | - 1.000 | -0.991 | 0.909 | - 1.141 | +0.141 |
| NULL | 0.000 | -0.085 | | - 0.098 | +0.098 |
| + 3 | + 1.000 | +0.828 | 0.913 | + 0.953 | +0.047 |
| + 6 | + 2.000 | +1.724 | 0.896 | + 1.985 | +0.015 |
| + 9 | + 3.000 | +2.619 | 0.895 | + 3.015 | -0.015 |
| +12 | + 4.000 | +3.516 | 0.897 | + 4.048 | -0.048 |
| +15 | + 5.000 | +4.412 | 0.896 | + 5.079 | -0.079 |
| +18 | + 6.000 | +5.308 | 0.896 | + 6.111 | -0.111 |
| +21 | + 7.000 | +6.202 | 0.894 | + 7.140 | -0.140 |
| +24 | + 8.000 | +7.098 | 0.896 | + 8.172 | -0.172 |
| +27 | + 9.000 | +7.993 | 0.895 | + 9.202 | -0.202 |
| +30 | +10.000 | +8.879 | 0.886 | +10.222 | -0.222 |

Pitch (Nonsensitive) Axis Output Voltage: +9.757

OMT Reading: 279 deg 20 min 38 s Solar Constant: 50 percent

Angle: +30 deg Mask Used: Yes

Data Date: November 15, 1971 Test Engr.: D. D. Johnston

PLSS: ±30 deg Head Yaw Axis

| Command Angle, deg | Volts for Ideal S. F. 0.33333 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| -30 | -10.000 | -9.787 | 0.984 | -10.102 | +0.102 |
| -27 | - 9.000 | -8.803 | 0.989 | - 9.087 | +0.087 |
| -24 | - 8.000 | -7.814 | 0.979 | - 8.066 | +0.066 |
| -21 | - 7.000 | -6.835 | 0.972 | - 7.055 | +0.055 |
| -18 | - 6.000 | -5.863 | 0.963 | - 6.052 | +0.052 |
| -15 | - 5.000 | -4.900 | 0.960 | - 5.058 | +0.058 |
| -12 | - 4.000 | -3.940 | 0.966 | - 4.067 | +0.067 |
| - 9 | - 3.000 | -2.974 | 0.978 | - 3.070 | +0.070 |
| - 6 | - 2.000 | -1.996 | 0.986 | - 2.060 | +0.060 |
| - 3 | - 1.000 | -1.010 | 0.987 | - 1.043 | +0.043 |
| NULL | 0.000 | -0.023 | | - 0.024 | +0.024 |
| + 3 | + 1.000 | +0.961 | 0.984 | + 0.992 | -0.008 |
| + 6 | + 2.000 | +1.939 | 0.978 | + 2.001 | +0.001 |
| + 9 | + 3.000 | +2.911 | 0.972 | + 3.005 | +0.005 |
| +12 | + 4.000 | +3.871 | 0.960 | + 3.996 | -0.004 |
| +15 | + 5.000 | +4.840 | 0.969 | + 4.996 | -0.004 |
| +18 | + 6.000 | +5.811 | 0.971 | + 5.998 | -0.002 |
| +21 | + 7.000 | +6.785 | 0.974 | + 7.004 | +0.004 |
| +24 | + 8.000 | +7.765 | 0.980 | + 8.015 | +0.015 |
| +27 | + 9.000 | +8.746 | 0.981 | + 9.028 | +0.028 |
| +30 | +10.000 | +9.731 | 0.981 | +10.044 | +0.044 |

Pitch (Nonsensitive) Axis Output Voltage: +4.818

OMT Reading: 294 deg 22 min 17 s Solar Constant: 50 percent

Angle: 15 deg Mask Used: Yes

Data Date: November 16, 1971 | Test Engr.: D.D. Johnston

PLSS: ±30 deg Head | Yaw Axis

| Command Angle, deg | Volts for Ideal S.F. 0.33333 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| +30 | +10.000 | +10.015 | 1.042 | + 9.985 | +0.015 |
| +27 | + 9.000 | + 8.973 | 1.012 | + 8.947 | +0.053 |
| +24 | + 8.000 | + 7.961 | 1.009 | + 7.938 | +0.062 |
| +21 | + 7.000 | + 6.952 | 1.002 | + 6.931 | +0.069 |
| +18 | + 6.000 | + 5.950 | 0.993 | + 5.932 | +0.068 |
| +15 | + 5.000 | + 4.957 | 0.983 | + 4.942 | +0.058 |
| +12 | + 4.000 | + 3.974 | 0.973 | + 3.962 | +0.038 |
| + 9 | + 3.000 | + 3.001 | 0.979 | + 2.992 | +0.008 |
| + 6 | + 2.000 | + 2.022 | 1.003 | + 2.016 | -0.016 |
| + 3 | + 1.000 | + 1.019 | 1.018 | + 1.016 | -0.016 |
| NULL | 0.000 | + 0.001 | | + 0.001 | -0.001 |
| - 3 | - 1.000 | - 1.022 | 1.023 | - 1.019 | +0.019 |
| - 6 | - 2.000 | - '2.040 | 1.018 | - 2.034 | +0.034 |
| - 9 | - 3.000 | - 3.042 | 1.002 | - 3.033 | +0.033 |
| -12 | - 4.000 | - 4.016 | 0.974 | - 4.004 | +0.004 |
| -15 | - 5.000 | - 4.992 | 0.976 | - 4.977 | -0.023 |
| -18 | - 6.000 | - 5.972 | 0.980 | - 5.954 | -0.046 |
| -21 | - 7.000 | - 6.964 | 0.992 | - 6.943 | -0.057 |
| -24 | - 8.000 | - 7.977 | 1.013 | - 7.953 | -0.047 |
| -27 | - 9.000 | - 8.998 | 1.021 | - 8.971 | -0.029 |
| -30 | -10.000 | -10.044 | 1.046 | -10.014 | +0.014 |

Pitch (Nonsensitive) Axis | Output Voltage: +0.002

OMT Reading: 309 deg 49 min 36 s | Solar Constant: 68 percent

Angle: Null | Mask Used: Yes

Data Date: November 15, 1971 Test Engr.: D.D. Johnston

PLSS: ±30 deg Head Yaw Axis

| Command Angle, deg | Volts for Ideal S. F. 0.33333 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| +30 | +10.000 | +9.777 | 0.992 | +10.092 | -0.092 |
| +27 | + 9.000 | +8.785 | 0.983 | + 9.068 | -0.068 |
| +24 | + 8.000 | +7.802 | 0.983 | + 8.053 | -0.053 |
| +21 | + 7.000 | +6.819 | 0.978 | + 7.039 | -0.039 |
| +18 | + 6.000 | +5.841 | 0.979 | + 6.029 | -0.029 |
| +15 | + 5.000 | +4.862 | 0.968 | + 5.018 | -0.018 |
| +12 | + 4.000 | +3.894 | 0.962 | + 4.019 | -0.019 |
| + 9 | + 3.000 | +2.932 | 0.974 | + 3.026 | -0.026 |
| + 6 | + 2.000 | +1.958 | 0.987 | + 2.021 | -0.021 |
| + 3 | + 1.000 | +0.971 | 0.989 | + 1.002 | -0.002 |
| NULL | 0.000 | -0.018 | | - 0.019 | +0.019 |
| - 3 | - 1.000 | -1.004 | 0.986 | - 1.036 | +0.036 |
| - 6 | - 2.000 | -1.988 | 0.984 | - 2.052 | +0.052 |
| - 9 | - 3.000 | -2.966 | 0.978 | - 3.062 | +0.062 |
| -12 | - 4.000 | -3.930 | 0.964 | - 4.057 | +0.057 |
| -15 | - 5.000 | -4.892 | 0.962 | - 5.050 | +0.050 |
| -18 | - 6.000 | -5.861 | 0.969 | - 6.050 | +0.050 |
| -21 | - 7.000 | -6.836 | 0.975 | - 7.056 | +0.056 |
| -24 | - 8.000 | -7.825 | 0.989 | - 8.077 | +0.077 |
| -27 | - 9.000 | -8.815 | 0.990 | - 9.099 | +0.099 |
| -30 | -10.000 | -9.804 | 0.989 | -10.120 | +0.120 |

Pitch (Nonsensitive) Axis Output Voltage: -4.805

OMT Reading: 295 deg 08 min 00 s Solar Constant: 49 percent

Angle: -15 deg Mask Used: Yes

Data Date: November 16, 1971 Test Engr.: D. D. Johnston

PLSS: ±30 deg Head Yaw Axis

| Command Angle, deg | Volts for Ideal S. F. 0.33333 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| +30 | +10.000 | +9.045 | 0.879 | +10.413 | -0.413 |
| +27 | + 9.000 | +8.166 | 0.890 | + 9.401 | -0.401 |
| +24 | + 8.000 | +7.276 | 0.898 | + 8.377 | -0.377 |
| +21 | + 7.000 | +6.378 | 0.904 | + 7.343 | -0.343 |
| +18 | + 6.000 | +5.474 | 0.908 | + 6.302 | -0.302 |
| +15 | + 5.000 | +4.566 | 0.906 | + 5.257 | -0.257 |
| +12 | + 4.000 | +3.660 | 0.901 | + 4.214 | -0.214 |
| + 9 | + 3.000 | +2.759 | 0.912 | + 3.176 | -0.176 |
| + 6 | + 2.000 | +1.847 | 0.914 | + 2.126 | -0.126 |
| + 3 | + 1.000 | +0.933 | 0.908 | + 1.074 | -0.074 |
| NULL | 0.000 | +0.025 | | + 0.029 | -0.029 |
| - 3 | - 1.000 | -0.885 | 0.910 | - 1.019 | +0.019 |
| - 6 | - 2.000 | -1.791 | 0.906 | - 2.062 | +0.062 |
| - 9 | - 3.000 | -2.694 | 0.903 | - 3.102 | +0.102 |
| -12 | - 4.000 | -3.595 | 0.901 | - 4.139 | +0.139 |
| -15 | - 5.000 | -4.491 | 0.896 | - 5.170 | +0.170 |
| -18 | - 6.000 | -5.394 | 0.903 | - 6.210 | +0.210 |
| -21 | - 7.000 | -6.304 | 0.910 | - 7.258 | +0.258 |
| -24 | - 8.000 | -7.217 | 0.913 | - 8.309 | +0.309 |
| -27 | - 9.000 | -8.127 | 0.910 | - 9.356 | +0.356 |
| -30 | -10.000 | -9.030 | 0.903 | -10.396 | +0.396 |

Pitch (Nonsensitive) Axis Output Voltage: -9.761

OMT Reading: 279 deg 49 min 36 s Solar Constant: 68 percent

Angle: -30 deg Mask Used: Yes

Data Date: November 17, 1971 Test Engr.: D.D. Johnston

PLSS: ±30 deg Head Pitch Axis

| Command Angle, deg | Volts for Ideal S.F. 0.33333 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| -30 | -10.000 | -8.855 | 0.869 | -10.514 | +0.514 |
| -27 | - 9.000 | -7.986 | 0.876 | - 9.482 | +0.482 |
| -24 | - 8.000 | -7.110 | 0.878 | - 8.442 | +0.442 |
| -21 | - 7.000 | -6.232 | 0.879 | - 7.399 | +0.399 |
| -18 | - 6.000 | -5.353 | 0.881 | - 6.356 | +0.356 |
| -15 | - 5.000 | -4.472 | 0.880 | - 5.310 | +0.310 |
| -12 | - 4.000 | -3.592 | 0.880 | - 4.265 | +0.265 |
| - 9 | - 3.000 | -2.712 | 0.887 | - 3.220 | +0.220 |
| - 6 | - 2.000 | -1.825 | 0.886 | - 2.167 | +0.167 |
| - 3 | - 1.000 | -0.932 | 0.889 | - 1.106 | +0.106 |
| NULL | 0.000 | -0.050 | | - 0.059 | +0.059 |
| + 3 | + 1.000 | +0.832 | 0.882 | + 0.988 | +0.012 |
| + 6 | + 2.000 | +1.715 | 0.883 | + 2.036 | -0.036 |
| + 9 | + 3.000 | +2.595 | 0.880 | + 3.081 | -0.081 |
| +12 | + 4.000 | +3.470 | 0.875 | + 4.120 | -0.120 |
| +15 | + 5.000 | +4.344 | 0.874 | + 5.157 | -0.157 |
| +18 | + 6.000 | +5.227 | 0.883 | + 6.206 | -0.206 |
| +21 | + 7.000 | +6.116 | 0.889 | + 7.262 | -0.262 |
| +24 | + 8.000 | +7.002 | 0.886 | + 8.314 | -0.314 |
| +27 | + 9.000 | +7.890 | 0.888 | + 9.368 | -0.368 |
| +30 | +10.000 | +8.778 | 0.888 | +10.422 | -0.422 |

Yaw (Nonsensitive) Axis Output Voltage: -9.981

OMT Reading: 280 deg 23 min 33 s Solar Constant: 48 percent

Angle: +30 deg Mask Used: Yes

Data Date: November 17, 1971 Test Engr.: D. D. Johnston

PLSS: ±30 deg Head Pitch Axis

| Command Angle, deg | Volts for Ideal S. F. 0.33333 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| +30 | +10.000 | +9.477 | 0.966 | +10.089 | -0.089 |
| +27 | + 9.000 | +8.511 | 0.954 | + 9.060 | -0.060 |
| +24 | + 8.000 | +7.557 | 0.951 | + 8.045 | -0.045 |
| +21 | + 7.000 | +6.606 | 0.952 | + 7.032 | -0.032 |
| +18 | + 6.000 | +5.654 | 0.944 | + 6.019 | -0.019 |
| +15 | + 5.000 | +4.710 | 0.937 | + 5.014 | -0.014 |
| +12 | + 4.000 | +3.773 | 0.937 | + 4.016 | -0.016 |
| + 9 | + 3.000 | +2.836 | 0.944 | + 3.019 | -0.019 |
| + 6 | + 2.000 | +1.892 | 0.947 | + 2.014 | -0.014 |
| + 3 | + 1.000 | +0.945 | 0.950 | + 1.006 | -0.006 |
| NULL | 0.000 | -0.005 | | - 0.005 | +0.005 |
| - 3 | - 1.000 | -0.952 | 0.947 | - 1.013 | +0.013 |
| - 6 | - 2.000 | -1.895 | 0.943 | - 2.017 | +0.017 |
| - 9 | - 3.000 | -2.838 | 0.943 | - 3.021 | +0.021 |
| -12 | - 4.000 | -3.773 | 0.935 | - 4.016 | +0.016 |
| -15 | - 5.000 | -4.702 | 0.929 | - 5.005 | +0.005 |
| -18 | - 6.000 | -5.642 | 0.940 | - 6.006 | +0.006 |
| -21 | - 7.000 | -6.582 | 0.940 | - 7.007 | +0.007 |
| -24 | - 8.000 | -7.527 | 0.945 | - 8.013 | +0.013 |
| -27 | - 9.000 | -8.480 | 0.953 | - 9 027 | +0.027 |
| -30 | -10.000 | -9.436 | 0.956 | -10.045 | +0.045 |

Yaw (Nonsensitive) Axis Output Voltage: +5.310

OMT Reading: 293 deg 31 min 48 s Solar Constant: 49 percent

Angle: +15 deg Mask Used: Yes

Data Date: November 16, 1971 Test Engr.: D. D. Johnston

PLSS: ±30 deg Head Pitch Axis

| Command Angle, deg | Volts for Ideal S. F. 0.33333 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| +30 | +10.000 | +9.742 | 1.023 | +10.017 | -0.017 |
| +27 | + 9.000 | +8.719 | 0.986 | + 8.965 | +0.035 |
| +24 | + 8.000 | +7.733 | 0.981 | + 7.952 | +0.048 |
| +21 | + 7.000 | +6.752 | 0.976 | + 6.943 | +0.057 |
| +18 | + 6.000 | +5.776 | 0.963 | + 5.939 | +0.061 |
| +15 | + 5.000 | +4.813 | 0.951 | + 4.949 | +0.051 |
| +12 | + 4.000 | +3.862 | 0.944 | + 3.971 | +0.029 |
| + 9 | + 3.000 | +2.918 | 0.958 | + 3.000 | +0.000 |
| + 6 | + 2.000 | +1.960 | 0.977 | + 2.015 | -0.015 |
| + 3 | + 1.000 | +0.983 | 0.985 | + 1.011 | -0.011 |
| NULL | 0.000 | -0.002 | | - 0.002 | +0.002 |
| - 3 | - 1.000 | -0.983 | 0.981 | - 1.011 | +0.011 |
| - 6 | - 2.000 | -1.959 | 0.976 | - 2.014 | +0.014 |
| - 9 | - 3.000 | -2.919 | 0.960 | - 3.002 | +0.002 |
| -12 | - 4.000 | -3.864 | 0.945 | - 3.973 | -0.027 |
| -15 | - 5.000 | -4.806 | 0.942 | - 4.942 | -0.058 |
| -18 | - 6.000 | -5.763 | 0.957 | - 5.926 | -0.074 |
| -21 | - 7.000 | -6.734 | 0.971 | - 6.924 | -0.076 |
| -24 | - 8.000 | -7.710 | 0.976 | - 7.928 | -0.072 |
| -27 | - 9.000 | -8.695 | 0.985 | - 8.941 | -0.059 |
| -30 | -10.000 | -9.708 | 1.013 | - 9.982 | -0.018 |

Yaw (Nonsensitive) Axis Output Voltage: -0.0004

OMT Reading: 308 deg 30 min 59 s Solar Constant: 68 percent

Angle: Null Mask Used: Yes

Data Date: November 17, 1971 Test Engr.: D. D. Johnston

PLSS: ±30 deg Head Pitch Axis

| Command Angle, deg | Volts for Ideal S. F. 0.33333 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| +30 | +10.000 | +9.563 | 0.988 | +10.180 | -0.180 |
| +27 | + 9.000 | +8.575 | 0.963 | + 9.128 | -0.128 |
| +24 | + 8.000 | +7.612 | 0.956 | + 8.103 | -0.103 |
| +21 | + 7.000 | +6.656 | 0.953 | + 7.086 | -0.086 |
| +18 | + 6.000 | +5.703 | 0.950 | + 6.071 | -0.071 |
| +15 | + 5.000 | +4.753 | 0.938 | + 5.060 | -0.060 |
| +12 | + 4.000 | +3.815 | 0.936 | + 4.061 | -0.061 |
| + 9 | + 3.000 | +2.879 | 0.949 | + 3.065 | -0.065 |
| + 6 | + 2.000 | +1.930 | 0.956 | + 2.055 | -0.055 |
| + 3 | + 1.000 | +0.974 | 0.957 | + 1.037 | -0.037 |
| NULL | 0.000 | +0.017 | | + 0.018 | -0.018 |
| - 3 | - 1.000 | -0.943 | 0.960 | - 1.004 | +0.004 |
| - 6 | - 2.000 | -1.899 | 0.956 | - 2.022 | +0.022 |
| - 9 | - 3.000 | -2.850 | 0.951 | - 3.034 | +0.034 |
| -12 | - 4.000 | -3.786 | 0.936 | - 4.030 | +0.030 |
| -15 | - 5.000 | -4.718 | 0.932 | - 5.022 | +0.022 |
| -18 | - 6.000 | -5.663 | 0.945 | - 6.028 | +0.028 |
| -21 | - 7.000 | -6.612 | 0.949 | - 7.039 | +0.039 |
| -24 | - 8.000 | -7.566 | 0.954 | - 8.054 | +0.054 |
| -27 | - 9.000 | -8.525 | 0.959 | - 9.075 | +0.075 |
| -30 | -10.000 | -9.495 | 0.970 | -10.108 | +0.108 |

Yaw (Nonsensitive) Axis Output Voltage: -4.989

OMT Reading: 323 deg 31 min 48 s Solar Constant: 47 percent

Angle: -15 deg Mask Used: Yes

Data Date: November 17, 1971

Test Engr.: D. D. Johnston

PLSS: ±30 deg Head

Pitch Axis

| Command Angle, deg | Volts for Ideal S. F. 0.33333 V | Direct Volts ($V_0$) | Δ Volt per Increment | $\frac{V_0 K}{\cos \delta}$ | Ideal Volts, $\frac{-V_0 K}{\cos \delta}$ |
|---|---|---|---|---|---|
| +30 | +10.000 | +8.690 | 0.848 | +10.317 | -0.317 |
| +27 | + 9.000 | +7.842 | 0.856 | + 9.311 | -0.311 |
| +24 | + 8.000 | +6.986 | 0.868 | + 8.295 | -0.295 |
| +21 | + 7.000 | +6.118 | 0.870 | + 7.264 | -0.264 |
| +18 | + 6.000 | +5.248 | 0.868 | + 6.231 | -0.231 |
| +15 | + 5.000 | +4.380 | 0.874 | + 5.201 | -0.201 |
| +12 | + 4.000 | +3.506 | 0.877 | + 4.163 | -0.163 |
| + 9 | + 3.000 | +2.629 | 0.879 | + 3.121 | -0.121 |
| + 6 | + 2.000 | +1.750 | 0.881 | + 2.078 | -0.078 |
| + 3 | + 1.000 | +0.869 | 0.875 | + 1.032 | -0.032 |
| NULL | 0.000 | -0.006 | | - 0.007 | -0.007 |
| - 3 | - 1.000 | -0.879 | 0.873 | - 1.044 | +0.044 |
| - 6 | - 2.000 | -1.748 | 0.869 | - 2.075 | +0.075 |
| - 9 | - 3.000 | -2.615 | 0.867 | - 3.105 | +0.105 |
| -12 | - 4.000 | -3.478 | 0.863 | - 4.130 | -0.130 |
| -15 | - 5.000 | -4.337 | 0.859 | - 5.149 | 0.149 |
| -18 | - 6.000 | -5.200 | 0.863 | - 6.174 | -0.174 |
| -21 | - 7.000 | -6.063 | 0.863 | - 7.199 | -0.199 |
| -24 | - 8.000 | -6.924 | 0.861 | - 8.221 | +0.221 |
| -27 | - 9.000 | -7.785 | 0.861 | - 9.243 | +0.243 |
| -30 | -10.000 | -8.645 | 0.860 | -10.264 | +0.264 |

Yaw (Nonsensitive) Axis

Output Voltage: -10.038

OMT Reading: 278 deg 31 min 48 s

Solar Constant: 49 percent

Angle: -30 deg

Mask Used: Yes

# APPROVAL

# PRECISE LINEAR SUN SENSOR

By Danny D. Johnston

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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